EARSeL ACTIVITIES IN THE FIELD OF COASTAL ZONE MANAGEMENT

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ABSTRACT:

The European Association of Remote Sensing Laboratories (EARSeL) facilitates networking between laboratories with common interests. In order to stimulate international cooperation and definition of research projects in the field of coastal zone management, a EARSeL Special Interest Group (SIG) on "marine waters, inland waters and coastal zones" has been created. The purpose of this paper is to describe the activities of this group. This paper is intended to give a brief overview of some of the research activities of members of this SIG, some of which have been presented at EARSeL meetings and at recent Annual Conferences of the Association. For clarity, these have been grouped under the three headings "water quality", "coastal morphology" and "ecology and vegetation".

1. EARSeL AND COASTAL ZONE MANAGEMENT

EARSeL, the European Association of Remote Sensing Laboratories, is an association of about 300 laboratories from within greater Europe, and even a few from outwith these bounds, representing about 4000 individual scientists. Set up about twenty years ago to foster the interests of the remote sensing community, it acts as a pressure group to promote the interests of its members to such organisations as the European Space Agency, the European Commission and the Council of Europe (Allewijn, 1994). One of its roles is to facilitate networking between laboratories with common interests and to stimulate international cooperation and definition of research projects. One way in which it does this is through Special Interest Groups, SIGs, and the purpose of this paper is to describe the activities of one of these, that on "marine waters, inland waters and coastal zones".

The coastal zone is receiving particular attention at present, particularly in Europe, because of its extreme sensitivity to environmental impact, both natural and anthropogenic. It is both sensitive to and a good indicator of climate change. Nearly half the world's population live on or near the coast and many of the major cities are less than 50 m above sea level, so any changes will have considerable economic and social impact. Remote sensing is obviously an ideal tool for monitoring these zones, but because of their complexity, spatial, spectral and temporal, the challenge is particularly great. The International Geosphere-Biosphere Programme (IGBP) has initiated a "Land-Ocean Interactions in the Coastal Zone" (LOICZ) project as part of its efforts to understand the interactive physical, chemical an biological processes that regulate the total earth system. The overall goal of the project is to determine at regional and global scales the nature of the dynamic interaction between the land, ocean and atmosphere, how changes in the various compartments of the earth system are affecting the coastal zones and altering their role in the global cycles, to assess how future changes in this areas will affect their use by people and to provide a sound scientific basis for future integrated management of coastal areas on a sustained basis (LOICZ report, 1995).

The coastal zone is a highly dynamic region with a very wide range of spatial, spectral and radiometric variability. In principle, remote sensing should be an ideal tool to investigate and monitor these regions and provide useful input to management schemes, and it may seem surprising that relatively little use has been made of these techniques until fairly recently. The main reason is that many of the current remote sensing systems were originally designed for other purposes, and as such their specifications may not be ideal for such use. The spatial and temporal resolution of most current satellite data are usually too poor to study the subtleties of many coastal processes, but may be valuable for providing the context into which finer detail can be fitted. Modern imaging spectrometers flown on aircraft are beginning to be used to provide that detail, and improvements in the spatial and spectral resolutions planned for future space missions will hopefully provide routine data for operational management schemes. It would seem that a synergistic approach to the use of combined dat from a number of sources is highly relevant to studies in these environments.

In the first two years of its existence, a number of initiatives within the EARSeL SIG have taken place. Perhaps the most significant to date was the three day workshop entitled "Remote Sensing and GIS for Coastal Zone Management" held in October 1994 in Delft which attracted nearly 100 participants of over 15 nationalities, including representatives from ESA, EC-DGXII, JRC/EC, UNESCO and the Dutch National Institute for Coastal and Marine Management. The proceedings of this meetings (Janssen and Allewijn, 1994) contains about 45 contributed papers, and a selection of 18 of these were subsequently published in the Association's peer-reviewed journal, Advances in Remote Sensing. At this meeting a more structured discussion took place dealing with problems, strategies and actions needed in the field of remote sensing and coastal zone management, the results of which were published in a special report (Allewijn and Janssen, 1994). EARSeL also jointly sponsored, along with The Remote Sensing Society, a conference in Dundee in December 1995 entitled "The Application of Remotely Sensed data to Monitoring Coastal Processes" and will also be involved in a Summer School, also to be held in Dundee, in August 1997 on the subject "Monitoring Physical Processes in the Coastal Zone", in conjunction with which it is intended to hold a second workshop. Members of the group have also been involved in two or three "network" type applications for funding under some of the European programmes.

This paper is not intended to be a review of the subject of coastal zone monitoring, rather it is an attempt to give a brief overview of some of the research activities of members of this SIG, some of which have been presented at the above meetings and at recent Annual Conferences of the Association. For clarity, these have been grouped under the three headings "water quality", "coastal morphology" and "ecology and vegetation".

2. WATER QUALITY

2.1 State of the art

One of the more useful applications of remote sensing in coastal areas is to monitor the volume, nature, concentration, distribution and movement of suspended sediments and dissolved substances by making use of their surface expression in the visible, thermal infrared and even microwave parts of the electromagnetic spectrum. Effluent and pollution, discharges and run-off may, under favourable conditions, all be tracked, and movements of sediment, particulary those linked to coastal erosion or accretion, can be observed. Algal blooms are often associated with concentrations of nitrates from agricultural activities and toxic blooms may be prejudicial to the fishing industry. Oil slicks, both accidental and deliberate, can be observed and hopefully, in the not too distant future, they may be identified and logged in near-real time on an operational basis.

Oil slicks can be readily detected in SAR imagery because of the damping effect they have on the capillary surface waves. Much effort is being expended on developing automated systems for detection using for example the RAIDs processed ERS-1 data from West Freugh. Cloud and land areas are masked out and then likely areas (particularly in busy shipping lanes) are screened for evidence of illicit oil dumping or tank cleaning and the results supplied to the regulatory authorities such as the Coastguards and Marine Pollution Units (Slogget and Jory, 1995; Slogget, 1994; Bos et al., 1994). Large oil slicks can also be detected on AVHRR imagery. Both the thermal signature and pattern recognition techniques have been used to develop a "mixed oil slick recognition algorithm" which was set up and tested on data from the Haven tanker disaster in the Gulf of Genoa (Ulivieri and Borzelli, 1994).

In the field of optical remote sensing main obstacles for quantitative use in monitoring programmes are the lack of operational atmospheric correction procedures and standardized methods for calculation of water quality parameters from atmospherically corrected data (Van Stokkom et al., 1993). Determination of water quality parameters is generally based on (semi-)empirical methods. Analytical procedures and methods for integrating remote sensing with point measurements and numerical models are now under development in a number of recent projects.

For inland waters multi-temporally valid algorithms have been established for chlorophyll-a and cyanophycocyanin (Dekker, 1995). For the estimation of seston dry weight (suspended matter), Secchi depth transparency and vertical attenuation coefficients semi-empirical algorithms are available, requiring in situ measurements each time a remote sensing image is acquired. The estimation of aquatic humus (dissolved organic matter) is currently not possible for inland waters. Only through adequate knowledge of the inherent optical properties of all the other substances present in the water analytical algorithms for aquatic humus determination may become available.

Going from inland waters to marine waters several changes (mainly a decrease in concentrations) occur in the presence and abundance of the various components within the water. When (semi-)empirical methods are used in coastal zones, errors occur in the estimation of water quality parameters, amongst others due to changes in the water surface state.

A number of member laboratories have been studying algal blooms. These occur both in open waters (case 1 waters) and in the coastal regions (case 2 waters). Much of the earlier work has studied the ocean colour due to phytoplankton, algae and cyano-bacteria. These are environmentally important generally but the toxic algae are particularly important not only for the part they play in the fish chain but because, if the come ashore, they can also affect land animals and otherwise pollute the beach. Blooms can quite easily be identified in case 1 waters by simple band ratioing, but in coastal waters the presence of resuspended sediment and bottom reflectance complicates the analysis. It is found that the signatures obtained are very site-specific, and may vary with time. This makes it difficult to specify a general algorithm, as can be done for open waters, or to use such data to classify algae types without in situ data for that particular area.

Since the demise of the Coastal Zone Colour Scanner in 1986 no satellite ocean colour data has been available, but the delayed deployment of the SeaWiFS (Sea Wide Angle of View Scanner) and the imminent launches of ADEOS, carring OCTS (Ocean Colour and Temperature Scanner) and ENVISAT carying MERIS (Medium Resolution Imaging Spectrometer) should mean that data will become available in the future. Aircraft are particulary useful, however, for coastal monitoring. Not only is the spatial resolution more suited to such work, but the new hyperspectral scanners now being flown and the temporal flexibility of aircraft enable them to image subtleties not possible from satellites (Vaughan, 1995).

The National Rivers Authority regularly flies the coastline of England with a CASI system which is programmed to simulate the SeaWiFS channels. This data is being used at the Dundee Centre for Coastal Zones Research, together with other datasets such as AVHRR and its own VIFIS (Variable Interference Filter Imaging Spectrometer) data, in a feasibility study for the British National Space Centre on the operational use of EO data for algal bloom monitoring. Stockholm University has studied blooms in the Baltic using AVHRR and the Joint Research Centre in Ispra has mapped the biologically active areas in the Mediterranean from archived CZCS data (Barale and Schlittenhardt, 1994); Rud and Kahru, 1995).

Other projects being undertaken in Dundee, which have implications for coastal polution, is the development of an automatic ship detection system using RAIDS ERS-1 SAR data in near-real-time and the study of thermal outfalls (Vaughan et al., 1995).

Methods for derivation of water quality parameters from remote sensing data should not only be multi-temporally valid, but also be applicable to the data from different sensors. In view of the present developments towards airborne and in the near future even spaceborne imaging spectrometry systems, data processing techniques must be spectrally flexible and cover the whole spectral range and not only a limited number of bands.

2.2 Data infrastructure

Remote sensing techniques have good potentials for mapping and monitoring a number of water quality parameters. The reason that these techniques are not yet used at their full potential can partly be explained by poor information facilities and a poor infrastructure for acquisition, processing, archiving and distribution of remote sensing data. It is expected that improvements of these facilities will lead to a considerable increase in the use of remote sensing for water quality applications.

Recently a number of international (GEDN), European (GENIUS and CEO) and national (e.g. in the Netherlands NEONET) studies have been initiated to define and implement a remote sensing data infrastructure. With respect to water quality applications, evaluation of the scopes and the first results of the above mentioned studies yields a number of conclusions:

1. Requirements of the end-users should form the starting point for definition of the infrastructure for remotely sensed data.
2. Processing toolkits and data-assimilation techniques should be integrated within the overall remote sensing data infrastructure.
3. Besides technical aspects, organisational and data-management aspects should get more attention (e.g. meta information systems, help desks, facilities for coordination of data-acquisition).
4. A balance has to be found between an infrastructure for satellite data on the one hand and high resolution airborne data on the other hand.

It appears that in terms of user requirements a distinction has to be made between remote sensing experts who convert raw remote sensing data into water quality information, and other kinds of users who need water quality information (viz. directly useable water quality information derived from remote sensing data). There are also large differences in the wishes of project users in research and advisory organisations and the so-called "end users" (or water quality managers). Finally, when establishing a remote sensing data infrastructure it is advisable to make a distinction between non-real-time applications and real-time applications.

When designing a data infrastructure, image processing facilities only need to be realised at a number of remote sensing expert centres. From the remote sensing data infrastructure point of view, for the non-remote sensing expert it will only be necessary to ensure that the supplied remote sensing information is compatible with the GIS which will be installed for each manager

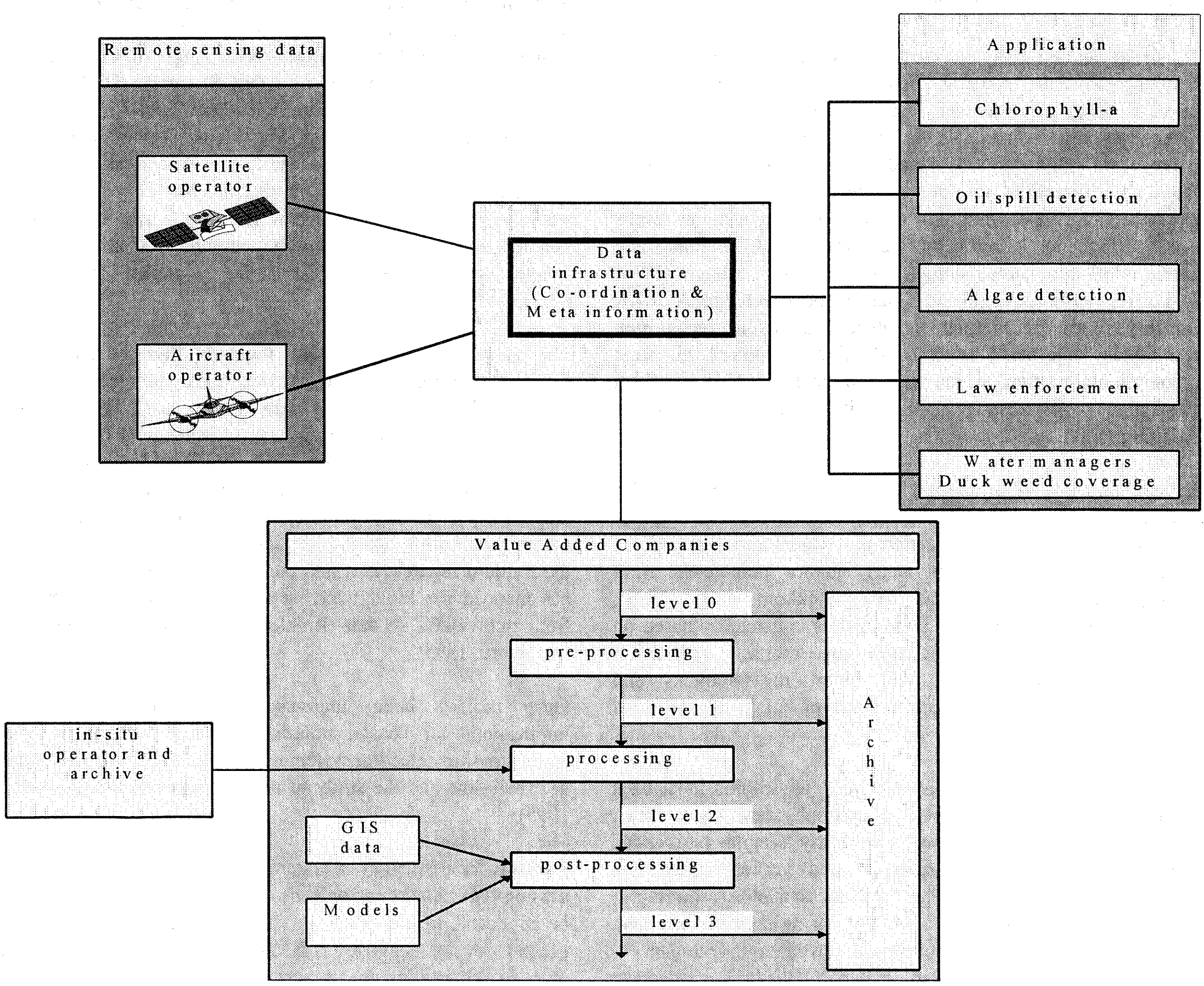

Figure 1: Functional design of remote sensing data infrastructure for water quality applications

in the not too distant future. Setting up a data infrastructure sufficient attention should be given to airborne data supply. Recent and present developments with respect to processing algorithms and data-integration should be incorporated within the European and national data-infrastructures. A number of stages of processing can be identified in this respect:

- preprocessing (e.g. geometric and atmospheric correction)
- processing (e.g. algorithm for deriving water quality parameters)
- post-processing (e.g. integration of remote sensing derived water quality products with numerical models and GIS)

The functional design of a data infrastructure for water quality applications is presented in figure 1. Operational use of remote sensing not only depends on the availability and flexibility of (spaceborne and airborne) platforms, but also on an efficient processing chain of the data. As compared to spaceborne data, (pre-)processing of airborne data is even more complex, especially with respect to geometric and atmospheric correction and corrections for the air-water interface. In general airborne remote sensing benefits from incorporation of a real-time dGPS system in the airborne platform, which will significantly reduce the pre-processing time.

Standard toolkits will not only reduce the time delay between acquisition and delivery of information to the end user, but also give more objective quality labels to the remotely sensed information. It is recommended to implement standard remote sensing (pre-)processing tools as public domain software at a number of governmental and commercial companies.

In general, during the summer months, a number of regional and local water managers are interested in remote sensing based water quality information of their region. A main bottleneck is that these water managers are not familiar with practical aspects related to the conditions for remote sensing flights. Furthermore, airborne remote sensing on a project basis for individual clients is in general too expensive. Consequently, operationalization of airborne remote sensing for water quality would benefit from coordinated data-acquisition, in which a value added company (or a consortium) contacts regional and local water managers, coordinates flights during the summer months, asks for offers from candidate airborne data-providers, distributes the raw data to (other) value added companies, etc.

Internet/WWW will play a very important role in the future satellite data infrastructure. Almost all satellite data providers are currently building meta information systems, including quick look browsing facilities. This development will have a tremendous impact on the accessibility of satellite data for the users. Satellite data sets have large volumes. Currently transfer of satellite data through Internet is not an option, although for smaller data volumes Internet technology can already be used (e.g. processed ERS SAR data for near real time oil spill detection). However, as high speed computer links will enable near real-time data distribution within a few years from now, the user group of "water quality" satellite data should keep an eye on these fast developments.

In an European context (CEO) and at national and institutional levels, meta information systems have to be developed, which form an information shell around data base systems containing remote sensing imagery. These shells must provide entrances and links to the actual data base systems where (raw) remote sensing data is kept. Furthermore, advertising the potentials of remote sensing through the Internet could create new users and products and stimulate (inter-)national cooperation between research groups and water quality managers. In this respect the EARSeL SIG on "marine waters, inland waters and coastal zones" can play a role in the context of CEO.

3. COASTAL MORPHOLOGY

3.1 Management problems

For sustainable development and management of sedimentary coastal plains, reliable and up-to-date geomorphological information is needed on the bathymetry of the near coastal zone and the height of the beach and coastal dunes. In this context for the manager of these lowland areas two main tasks can be identified: 1) management and maintenance of shipping lanes to ensure transport and distribution capacity and 2) protection of the inshore area against flooding.

For safety, efficiency and economic reasons there is a need for accurate and reliable depth information in navigation areas. With respect to the required type of bathymetric information a distinction can be made between two types of in-situ depth measurements: 1) monitoring of large scale morphodynamics and 2) small-scale surveys for management in depth-critical areas. Monitoring surveys are carried out to support long-term safety strategies. Depth measurements in shipping areas and dump locations contribute to short-term management and maintenance and they have a strong relationship with economic and legal responsibilities of the authorities.

In most lowland countries the foredunes, beaches and near coastal zone are monitored on a regular basis to assure that their primary function as defence against the sea is maintained. For instance in the Netherlands, as of 1964 the topography of the coast is measured in cross sections perpendicular to the coast line. The measurements consist of depth measurements of the near coastal zone and height measurements of the beach and foredunes. In total 1700 of such coastal profiles are measured yearly, through acoustic measurements and standard analytical photogrammetric means. Based on these observations it is decided where and how much sand is to be supplied. For the part five years, in the Netherlands "the dynamic maintenance of the coast line" is the guiding principle, indicating that some freedom is allowed for the dynamic processes to take place.

Knowledge of the actual depth of the sea bottom and shipping lanes and the height of the coastal defense works is fundamental to take corrective actions, if necessary. In practice this means that either sand nourishment or channel dredging is carried out. On a long term basis morphodynamical information is used to make predictions of future morphological changes. This type of information is used to formulate a long-term strategy towards coastal defense matters.

Besides its function to protect the lowland against flooding, the sandy coastal area unites a number of other important functions. The dune area serves as an important reservoir proving drinking water to cities. Another important aspect concerns tourism and recreation. Also claims are exerted on the coastal area with respect to housing, industrial and agricultural activities. And, last but not least, the coastal zone is of paramount importance in view of the ecological infrastructure and nature conservation. With respect to the latter the emphasis is shifting from rigid maintaining of the present situation to allowing dynamic processes to take place and even to actively restore dynamic processes in the area. Through integral management one tries to involve and balance the various interest groups and co-ordinate their activities. Up to date information is required to effectively carry out the managerial task concerned.

3.2 A new bathymeric surveying method

The traditional technique to measure sea bottom morphology, using in-situ shipborne echo sounders, is expensive and time consuming. Based on nearly 10 years of fundamental and application research an innovative method has been developed using radar satellite images, hydro-dynamical models and a limited set of in-situ depth measurements to assess a bottom depth chart (Vogelzang et al., 1994). Under favourable meteorological and hydrodynamic conditions (moderate winds of 3 to 5 m/s and tidal currents of about 0.5 m/s), airborne or spaceborne Synthetic Aperture Radar (SAR) imagery shows features of the bottom topography of shallow seas to a maximum depth of approximately 30 m. The imaging mechanism of mapping sea bottom topography by imaging radar consists of three stages (e.g. Calkoen et al., 1993):

- Interaction between (tidal) flow and bottom topography results in modulations in the (surface) flow velocity. This relation can be described by several models with an increasing level of complexity (continuity equation, shallow water equations, and the Navier Stokes equations).
- Modulations in surface flow velocity cause variations in the surface wave spectrum. This is modelled with the help of the action balance equation, using a source term to simulate the restoring forces of wind input and wave breaking.
- Variations in the surface wave spectrum cause modulations in the level of radar backscatter. To compute the backscatter variations a simple Bragg model can be used.

Based on the above three physical mechanisms, a suite of models has been developed and operationalized. This suite of numerical models generates the radar backscatter given the bathymetry and the wind. Because the parameter of interest is the bottom depth it is necessary to invert this depth-radar backscatter relation. Therefore, a data assimilation scheme has been developed, minimizing the difference between the calculated and the measured radar backscatter by adjusting the bottom topography (figure 2).

In 1995 a study has been performed to test the method on accuracy, reliability, cost-effectiveness in a "pseudo" operational situation. Test sites with various specific morphologic features, such as shipping lanes, intertidal flats and shallow water sand waves, were chosen in the Wadden Sea area and in the Netherlands foreshore area near Rotterdam harbour. The most important results are :

- Multi-temporal analysis of SAR imagery improves the accuracy of depth assessments, up to a level comparable to that of traditional methods, i.e. 30 cm depth accuracy for monitoring surveys;
- The use of radar remote sensing techniques may reduce traditional monitoring survey efforts with a factor of approximately 50 %.

Developing and implementing a method like this as an operational production process is a time- and money consuming business. The costs of fundamental and application research are estimated to be 1.5 million Dutch guilders, while the system development and implementation costs approach nearly 3 million guilders in 5 years time. So, the total investment on research and development approaches 5 million guilders over a period of 15 years (1987-2001). When fully operational this system will reduce the government expenses on monitoring surveys from 2 million to 1 million a year, therefore a yearly cost-reduction of 1 million is obtained. It is expected that the return on investment of this system will be reached after 5-7 years.

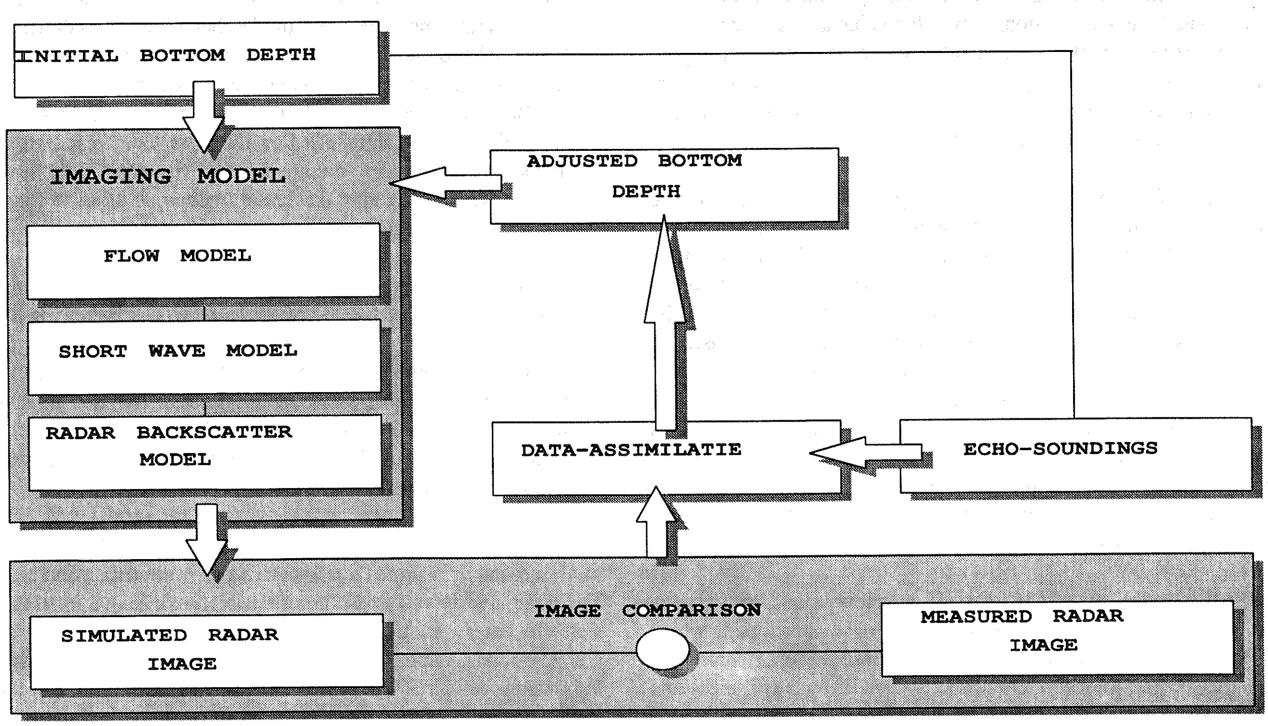

Figure 2: Outline of remote sensing based bathymetric assesment system

3.3 Laser scanning for height measurements

In the Netherlands and Belgium the coastal zone managers are considering the introduction of laser technology to derive height information for the beach and coastal dune area. This new technique will provide the necessary data sets for coastal zone management, aiming both at the reduction of costs and the improvement of the products. Laser scanning will provide an elevation model of the sandy coast. From the resulting digital elevation model (DEM) profiles of the beach and foredunes will be extracted on a yearly basis, replacing the costly and time consuming determination of profiles through photogrammetric means. At the same time the laser scanning data, covering an area in total, provides an opportunity to assess more accurately the volumes of sand having been eroded from beach and foredunes.

For the inner dune area the elevation data will allow changes to be monitored, for example with respect to erosion and accretion of sand and to study morphological processes. However, in many parts the construction of an accurate model of the ground surface elevation is hampered by dense vegetation cover. The main objective is therefore to provide a general overview of the area, of benefit to the manager. To this end the laser DEM will be combined with imagery providing thematic information, such as land cover. The imagery will be obtained from airborne digital video. Main consideration for the selection of video, among alternatives like aerial photography and optical line scanners, is the relative by low cost. However, the savings realised with respect to the imagery might be annulled by the increase of cost for the further processing of the video data (e.g. geometric correction and mosaicing) and should be further investigated. Another disadvantage is the relative by low resolution of the video imagery in comparison to aerial photography. The user will decide in this respect whether video imagery satisfies his demands.

The laser DEM and video data will be placed in a GIS environment with specific tools to allow the user to integrate depth and height measurements of the coast, extract cross sections of the coastal zone, assess the quality of elevation models derived and to generate bird's eye views of areas one is interested in.

In 1995 a number of experiments were performed to assess the accuracy and reliability of the laser technique for DEM acquisition as well as to gain insight in its operational aspects. Large project areas were appointed in several parts in the Netherlands along the coast and estuaries, the most important being the group of Frisian Islands in the north. The total area involved several hundreds of square kilometres. The quality demands were specified as following:

- point density 1 per 16 m^2;
- a maximum systematic error of 5 cm;
- a precision of 15 cm (standard deviation) for non-covered or sparsely vegetated areas;
- a precision of 20 cm (standard deviation) for areas covered with dense vegetation;

In every project area, small patches were chosen where control measurements were carried out, both for checking on point density as well as assessing the geometric quality by simple statistical means. Furthermore, laser derived coastal profiles were compared with the photogrammetric derived coastal profiles. In figure 3 the results of such a comparison are presented, made between 132 photogrammetrically surveyed coastal profiles of the island of Ameland, and the laser profiles. The latter are generated by interpolation from a regular grid of laser points to the planimetric co-ordinates of the profile points. For each profile differences are then calculated between the interpolated laser heights and the corresponding photogrammetric heights. From these differences, a systematic offset and a RMS error can be calculated for each of the 132 profiles. In figure 3, the X-axis gives the position of a profile along the coast, in kilometres from the most western point of Ameland. On the Y-axis, the systematic offset and the RMS error are given in meters above Mean Sea Level. The RMS error is generally about 15 cm in magnitude. The systematic offset starts low in the west (between kilometre 1 and 3), then suddenly increases to 15-20 cm.

The results turned out to be slightly disappointing, as in general the quality demands were not met. Systematic offsets larger than 10 cm occurred, together with RMS errors of more than 20 cm in magnitude. For assessing sand volumes at the beach, these are unacceptable figures. Also, many parts of the delivered DEMs showed the presence of remaining large outliers, that had not been filtered out, due to a too inflexible filtering method applied and the complexity of the terrain topography, which the laser scanner could not handle properly.

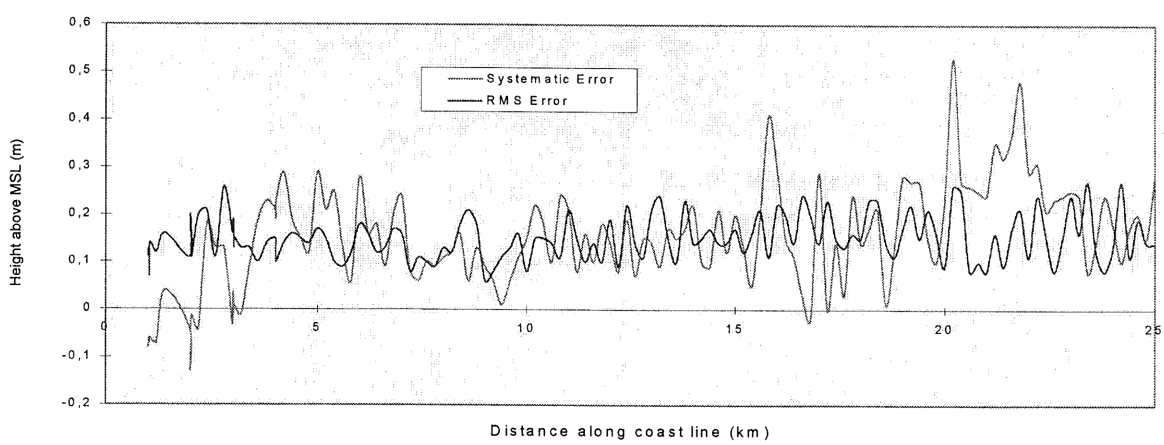

Figure 3: Differences between photogrammetrically surveyed coastal profiles and laser profiles

In trying to explain the presence of the errors encountered, several error sources could be traced, part of which were of such nature that allowed corrections to be made by reprocessing the raw laser data. This was true for errors related to the registrations by the inertial navigation system (INS) and interaction between laser beam and glass plate. Another systematic error source concerned the transformation between the WGS'84 co-ordinate system and the Netherlands National Reference System, a transformation that was not defined with sufficient accuracy.

The terrain type and dense vegetation cover in some areas caused the largest devaluation of accuracy and point density. In these areas the laser was simply unable to hit the ground. As a consequence, systematic offsets of several tens of centimetres were found to be present between laser data and control points. As these offsets varied for different control areas, even in the case that areas had the same type of vegetation cover, no means were at hand to apply a valid correction for them. The terrain relief influences the degree in which the laser data can describe the terrain surface. With a point density of 1 per 16 m^2, small scale variations may be missed. Furthermore, sudden changes in the terrain surface, like steep dike slopes, were partly filtered out, as the filtering program assumed these to be a terrain surface anomalies. So here the filtering had been too severe, which once again shows that no standard filtering algorithm can be used for all parts and that additional terrain information must be added.

Based on the experienced gained during the 1995 test flights it was still concluded that laser scanning is a powerful cost-effective technique and that highly accurate data can be generated. Therefore, in 1996 new test flights will be performed for the total Dutch coast. The results will be compared with the traditionally derived photogrammetric coastal profiles. If the accuracy and reliability of the laser derived beach profiles are comparable with the traditional measurements, laser scanning will be implemented from 1997 onwards as an operational procedure to replace the photogrammetric production process. This will lead to a cost reduction of 1.2 million guilders a year.

Recently, other attemps at producing DEMs for coastal areas using SAR data have been undertaken. Davenport reported, at one of the recent EARSeL meetings, his work using multitemporal data and tide-heigh data to plot contours in the intertidel region. This method actually exploits the non-synchronicity of ERS overflights with the tidal cycle. Work is also going on in Dundee to examine the use of interferometric SAR (INSAR) to study morphological changes in the castal regions and to map changes to estuarine sandbanks and saltflats from processed SAR data.

4. ECOLOGY AND VEGETATION

4.1 Management problems

Vegetation information is used by policy makers and managers of nature areas as an indicator of the ecological condition of the terrain. The species composition and the vegetation structure are determined by the site conditions. These conditions are the result of action and interaction of all biotic and abiotic factors (viz. climatic, geological, geomorphological, hydrological and soil conditions and the effect of fauna and human influence) active at a particular site. This is called the system (or holistic) approach to vegetation. In time this relational complex may change due to natural or human induced processes and the vegetation reacts accordingly. Hence the role of vegetation maps in monitoring programmes is to reveal which processes are active where and, in the case of sequential mapping, what is the progression speed of these processes. By evaluating the observed changes a manager can decide whether it concerns a desirable or undesirable development in relation to the management aims of an area and management practices may be adapted accordingly. Remote sensing (including aerial photographs) has since long proven to be

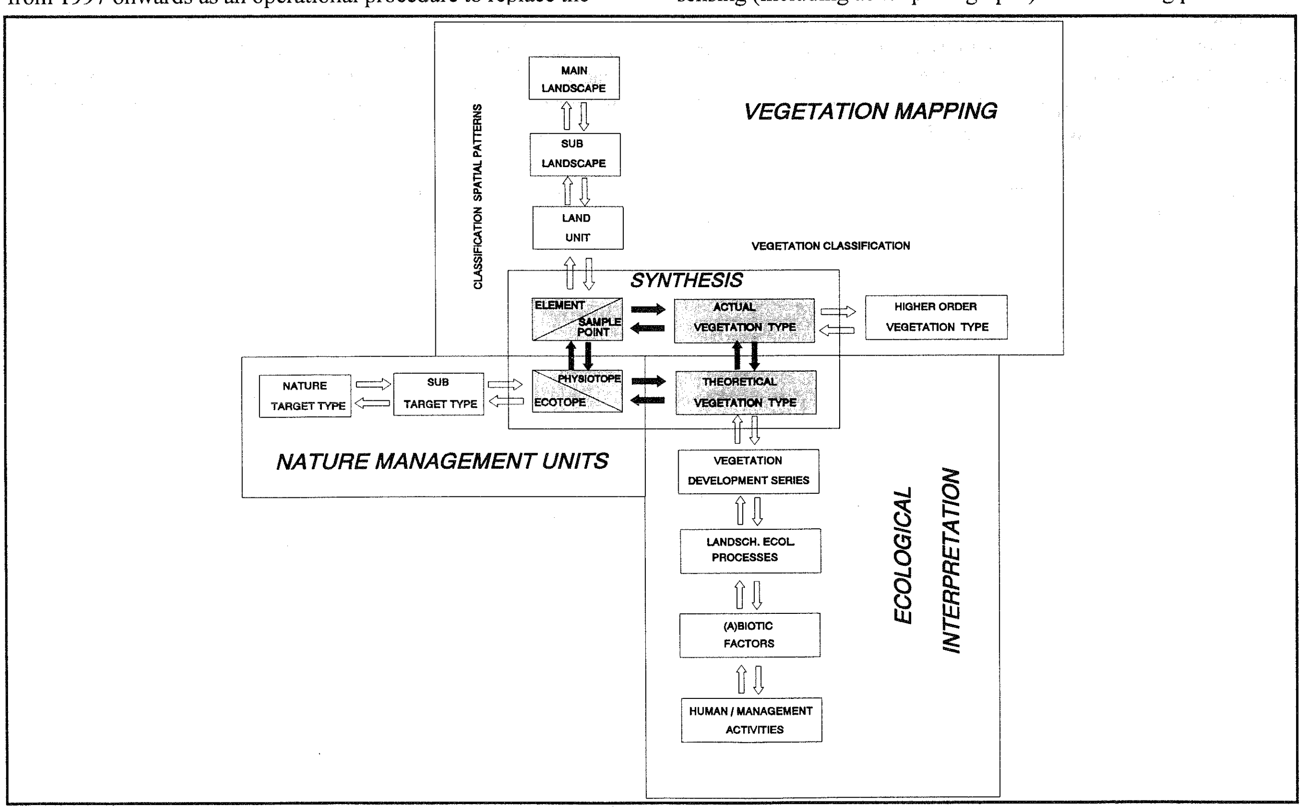

Figure 4: The main components in mapping and monitoring of coastal ecosystems

a very useful tool for vegetation mapping. Examples can be found in a variety of landscapes in literally every country in the world.

One of the main problems in the practical application of remote sensing for vegetation mapping is that not all relevant landscape ecological processes are active at the same level of detail in the landscape. The effect of desiccation and decalcification on the vegetation of a dune slack must be monitored at a larger scale than the invasion of Sea Couch (Elymus pycnanthus) on salt marshes or changes in the total area covered by saltmarsh vegetation in the Waddensea. If the scale of a vegetation map is not geared to the detail level of the information requirements, a manager may end up with a too detailed or too general map.

4.2 A conceptual basis for mapping and monitoring of coastal ecosystems.

At the Survey Department a method has been developed to translate landscape ecological processes into vegetation development series, map these series at various scales with different remote sensing techniques and provide managers and policy makers means to decide if a specific problem can be tackled by remote sensing and if so, which will be the appropriate scale and survey frequency (Kloosterman et al, 1995; Janssen et al, 1996). This method comprises three main components (see figure 4):

1. Nature management: What are the management problems and aims?
2. Vegetation mapping: What can be depicted with remote sensing?
3. The ecological interpretation: What is the ecological meaning of the observed vegetation changes in relation to the management problems and aims?

These components must be tuned in such a way that the information on a map, the information presented by the ecological interpretation and the information requirements set by nature managers or policy makers are interchangeable at a certain level. In other words since management as well as mapping ultimately deal with concrete areas, the information on a map as well as ecological interpretation of this information must be translatable to the concrete areas for which a particular management practice is imposed. In figure 4 this translation level is indicated by the word "synthesis". The central unit within the synthesis is the ecotope or physiotope. An ecotope is defined as the smallest, ecologically homogeneous unit in a landscape (Zonneveld, 1979; Naveh and Lieberman, 1984; Haines-Young et al., 1993). A physiotope is the abiotic part of an ecotope or ecosystem and is homogeneous for a number of abiotic factors (Stordelder and Hommel, 1990). Both a concrete management unit and a unit on a vegetation map can be considered as landscape units consisting of one or more ecotopes or physiotopes. Hence the management units and mapping units are interchangeable on this level. The essence of the ecological interpretation is to provide a framework of (theoretical) vegetation types, indicative for stages in the progress of landscape ecological processes (eg. desalinisation, land subsidence, eutrophication). By assessing the similarity between the actual vegetation and the theoretical vegetation types, the former can be translated into a progression stage of a landscape ecological process.

By presenting vegetation development series at the ecotope/physiotope level, the ecological interpretation can be translated directly to the management component. The last step is to asses at which scale the vegetation types, indicative for particular landscape ecological process, can be monitored sufficiently homogeneous and which remote sensing technique is most appropriate (see table 1).

It is believed that the conceptual framework developed at the Survey Department is not area specific and is broadly applicable for mapping and monitoring of coastal ecosystems. The required scale depends on area specific conditions (eg. diversity and area covered by per vegetation type) and level of detail of the required management information. The smaller the scale, the more appropriate satellite remote sensing becomes. Digital images are more suitable for quantitative monitoring than changes assessed by visual interpretation of analogue aerial photographs. In general however, digital spectral information alone is not a sufficient basis for a meaningful classification of coastal ecosystems. Analogue (aerial photographs) remain an important tool for a

indicative vegetation type	actual vegetation type	aerial photograph 1:2.000	aerial photograph 1:5.000	aerial photograp h 1:18.000	CAESAR 0.75x0.75m	SPOT 10x10m
		false colour	false colour	B/W PAN	multi spectral airborne scanner	multi spectral spaceborne scanner
Sueda maritima community	Sueda maritima type	+	+	-	-	-
Atriplex litoralis community	Atriplex prostrata type	+	+/-	-	+/-	-
Puccinellia maritima community	Puccinellia maritima type	+	+	+/-	+/-	-
Artemisia maritima community	Artemisia maritima type	+	+	+/-	+	+/-

Table 1: "Mappability" of indicative vegetation types

significant, landscape ecological stratification (Kloosterman et al., 1995; Janssen et al., 1996). Hence the optimal use of the potential of digital images is achieved in combination with a stratification on the basis of visual stereoscopic interpretation of aerial photographs.

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