# Extraction of Beach Landforms from DEMs using a Coastal Management Expert System

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## Abstract

This paper describes the use of a prototype coastal management expert system, to facilitate the extraction of a salient element of coastal landforms from a DEM derived from stereo aerial photography. The system, COAMES (COAstal Management Expert System), is currently under development at Plymouth Marine Laboratory and the University of Plymouth. The sub-landform to be extracted is identified and isolated through use of "intelligent" ground control points stored within COAMES' object-oriented data structure, in conjunction with geomorphological rules and functions embedded in COAMES' hierarchical knowledge structure. The morphology of this extracted feature is modelled using polynomial functions - this can be compared with a similar feature extracted at a different time to gain a picture of geomorphic feature development.

## 1. Introduction

There has been a recent and radical increase in the magnitude, speed and economics of high performance computing which has unlocked potential for computationally intensive analysis of a geographical nature. Amongst the generic applications that are set to benefit from this increased capability are artificial intelligence techniques, replacing conventional modelling tools (Openshaw & Abrahart 1996). Artificial intelligence itself has received an explosion of interest in the last five years and it is apparent that constituent areas such as expert systems will be integral in the evolution of the next generation of GIS (Fischer 1994).In Moore *et al.* (1996), a conceptual outline of an expert system was put forward for coastal zone management, an area in which there has been very little research compared with other disciplines in the geosciences. It follows that the application of expert systems to coastal zone management is unique. The expert system, COAMES (COAstal Management Expert System), strives to integrate knowledge and data into an object-oriented structure, whilst keeping the inference engine and knowledge base components of the expert system as separate entities. This provides a consistent platform to which the coastal zone manager can proffer queries and hypotheses, using the output and a holistic approach to gain a better understanding of the coast. Since this conceptual outline, the initial efforts in building COAMES have concentrated on developing a prototype covering a narrow domain in coastal expertise. This method of rapid prototyping is expedient where there is a high degree of uncertainty in the specification (Fedra & Jamieson 1996). The area of application is coastal geomorphology, more specifically the identification of beach features on a stretch of rapidly eroding coast in Eastern England (Holderness). Firstly, this paper details the preparation of digital elevation models (DEMs) of the study area through digital photogrammetric methods, before outlining the structuring and processes that operate within COAMES. This is done with specific reference to the operation of 'intelligent' ground control points and implementation of morphometric functions held as objects within the structure. These are used to locate and delineate a specific geomorphological feature. Finally, there is a discussion on such issues as error and uncertainty, scale and modelling structures.

## *2. Background*

### 2.1 Expert Systems

Expert systems can be regarded as the most mature products to emerge from the field of artificial intelligence (Raggad,1996), dating back to the mid-1960s. A representative definition states that expert systems "....advise on or help solve real-world problems requiring an expert's interpretation and solve real-world problems using a computer model of expert human reasoning reaching the same conclusion the human expert would reach if faced with a comparable problem." (Weiss & Kulikowski, 1984). There has been much research into the use of expert systems in geography. However, progress has been slow when compared to other subject areas, mostly due to the complex nature of geospatial problems (Fischer,1994). Having said this, the potential of expert systems is great, based on the extent to which they have been adopted in a multidisciplinary context (Durkin 1996). Indeed, very recently, expert systems have proved to be valuable in another environmental discipline, geology, where the volume of data and the complexity of processing means that 3D analysis needs computer assistance. Also the field is sufficiently huge that 'few individuals have mastery over the whole' (Ferrier & Wadge, 1997). There have been very few expert systems with a coastal application. The Ocean Expert System (Dantzler & Scheerer, 1993; Scheerer, 1993) was developed for tactical oceanography, to acquire, interpret and manage oceanographic information. A main consideration of the system was to exploit incomplete and uncertain coastal environmental information, predominantly through the Dempster-Schafer theory of belief.

### 2.2 Object Orientation

It has been said that there are three conceptual models to represent knowledge in an expert system - rule-based, frame-based and blackboard architecture (Kartikeyan, Majumder & Dasgupta, 1995). Historically, the rule-based model has been the most popular, though what is of interest here is the frame-based or object oriented model. Raper and Livingstone (1995) have outlined a rationale for using object-oriented techniques: it has been argued that an object-oriented paradigm (where reality is modelled through the attributes and functions relating to objects) makes considerable progress towards letting the application domain uniquely define the form of the computer model (Raper & Livingstone 1995). Conventionally in environmental modelling, the representational basis of a GIS, for example, is often allowed to drive the form and nature of the model. Ferrier & Wadge (1997) also explore avenues of possibility with object orientation, reasoning that it provides a means of structuring more complicated types of knowledge base than rule based systems.

### 2.3 Coastal Zone Management

The coastal zone is a unique environment where conflicting interests meet; developmental, recreational, industrial (e.g. in mineral extraction) and conservational (DoE 1995). Management is a question of reconciling these differing viewpoints. Figure 1 portrays the sociological side of coastal zone management, which enables a look at the role of an expert system in a wider context. From a sociological point of view, the coastal zone manager liaises with the coastal zone stakeholders, each having their own concerns and applications. These stakeholders will almost certainly be a fount of coastal knowledge in themselves, which they can impart to the expert system, possibly via the Internet. The conflicting applications of the stakeholders are weighed up by the coastal zone manager and fed into the system (Fig.5) via a dialogue. Based on this, the relevant knowledge and data is invoked, inferred with reference to the initial query and decision support output returned for assessment. If the output is acted upon, then cyclical monitoring of the resultant situation in the coastal zone takes place. Through use of the expert system, the manipula-

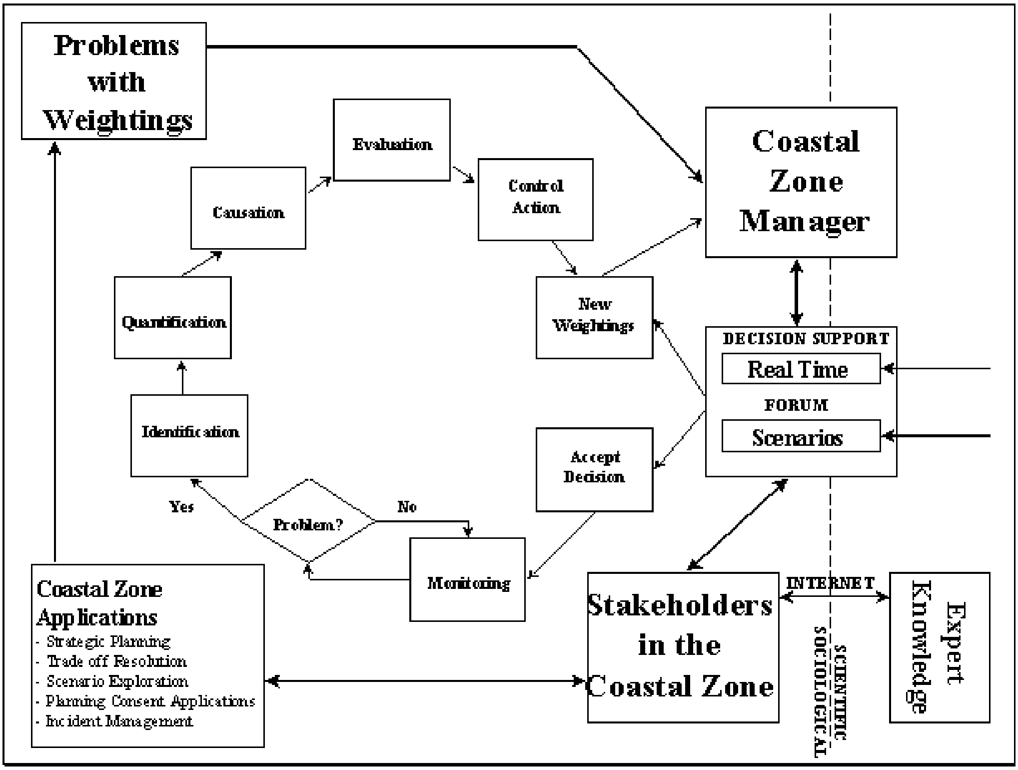


***Fig.1:*** *The sociological component of coastal zone management*

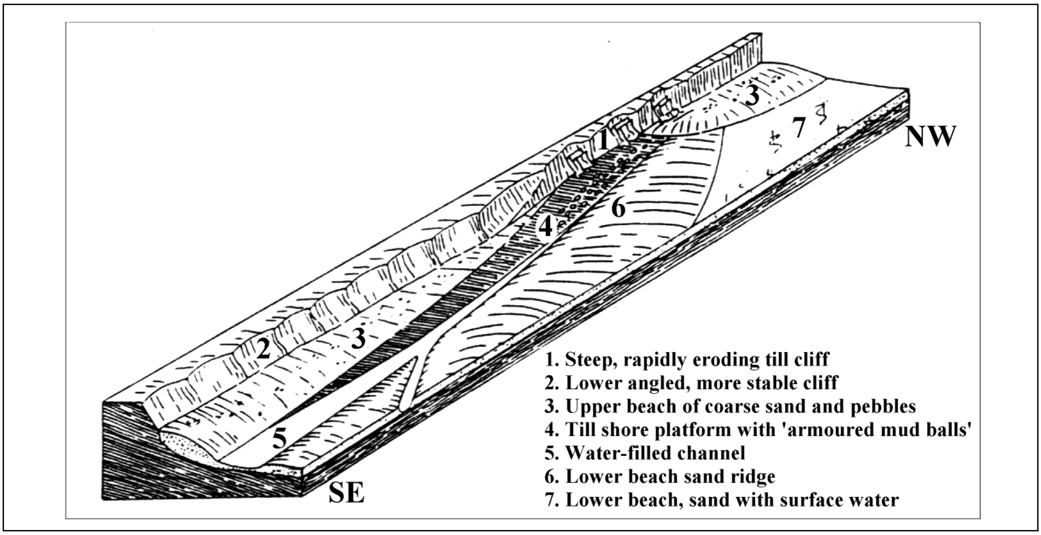


***Fig.2:*** *The characteristic features of a Holderness ord (from Pringle 1985).*


*Fig.3:* *Aerial photograph of the Holderness coast near Easington with superimposed ground control and tie points. Taken 26/10/96.*

tion of spatial and aspatial data can be seen as a means by which effective coastal zone management can be aided. The role of such data and knowledge is to form a comprehensive platform from which informed and optimal decisions can be made on matters pertaining to the coastal zone.This is one of the main reasons why a system such as COAMES is of potential value.

### 2.3.1 Geomorphological Background of the Study Area

The geomorphic application chosen for this prototype reflects the conservational / natural side of coastal zone management.The area of study is the Holderness coast in northeast England, which is backed by glacial till cliffs and subject to a very rapid rate of erosion (1.2m/yr).This erosion is even more rapid where there are low sections of beach, exposing areas of till platform.These are associated with composite ridge-type beach landforms called ords, the structure of which is shown in Fig.2.These landforms migrate along the direction of longshore drift (Pringle, 1985).

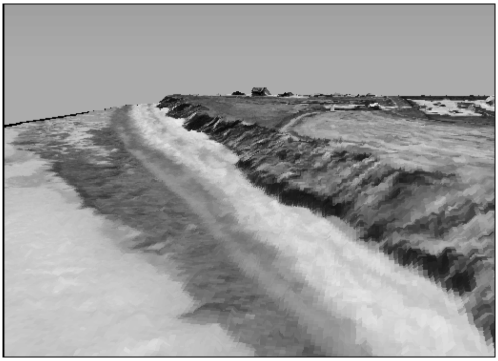

*Fig.4:* *DEM covering part of Figure 3. The salient elements of the beach can clearly be seen, from the sand ridge on the left, through the darker till platform to the steeper upper beach banking the till cliffs.*

## 3. Methodology

### 3.1 Using Digital Photogrammetry to Derive the DEM

Two aerial photographs were chosen so that the derived area of stereo overlap captured the distinct elements of one of the ords, and also so that the same area of the coastal strip was available at another time for future processing.The two times chosen were October 1996 (see Figure 3 for example) and April 1997, theoretically covering the period of most radical geomorphological change.

After prerequisite scanning, the photos were used as input into ERDAS Imagine's digital photogrammetry module, ORTHOMAX (for an overview of digital photogrammetry see Petrie 1996). Firstly, the precise positions of the two photographs in modelled computer space were pinpointed through the digitisation of their respective fiducial marks and correction for camera distortion (inner orientation). A further stage (relative orientation) orients the two photographs relative to each other through the identification of the same salient features (tie points) on both. The last stage of orientation is the modelling of the stereo pair to real ground co-ordinates in Latitude-Longitude or National Grid format and altitude (absolute orientation). A good spread of these co-ordinates (or ground control points) is advised across the area of stereo overlap for the optimum photogrammetric model. These known points were derived from surveyed benchmarks and differential Global Positioning System (GPS) surveys, some of which were undertaken in conjunction with the aerial photography sorties. Associated with each ground control point measured was a description of the topology of the beach features there. It is this that is used by the expert system to locate salient elements on the beach from the DEM, which was constructed itself after stereo matching of the stereo pair. Figure 4 shows the DEM for October 1996 overlain with an orthorectified photograph (adjusted to ground co-ordinates).

### 3.2 Construction of the Expert System

The design of the expert system was true to the original schematic as set out in Moore *et al* (1996), which is shown in Figure 5. Briefly running through the elements and processes that underlie COAMES, an initial query prompts the interface to extract the operative words and passes them to the inference engine, which performs logical processes (e.g., induction, deduction) to select data, knowledge and models appropriately. The last role of the inference engine is to select an appropriate method for visualising the results of the query.

#### 3.2.1 The Hierarchical Knowledge Structure

Figure 6 displays the configuration of the class structure of the geomorphological prototype COAMES. Classification involves the assignment of individual occurrences defined on the basis of selected attributes or functions. All classes will have specific attributes unique to themselves (Laurini & Thompson 1992). For instance, the raster subclasses slope, aspect and convexity are defined by their attributes and functions; these are encapsulated within the class definition. In addition, they inherit all the elements of the raster

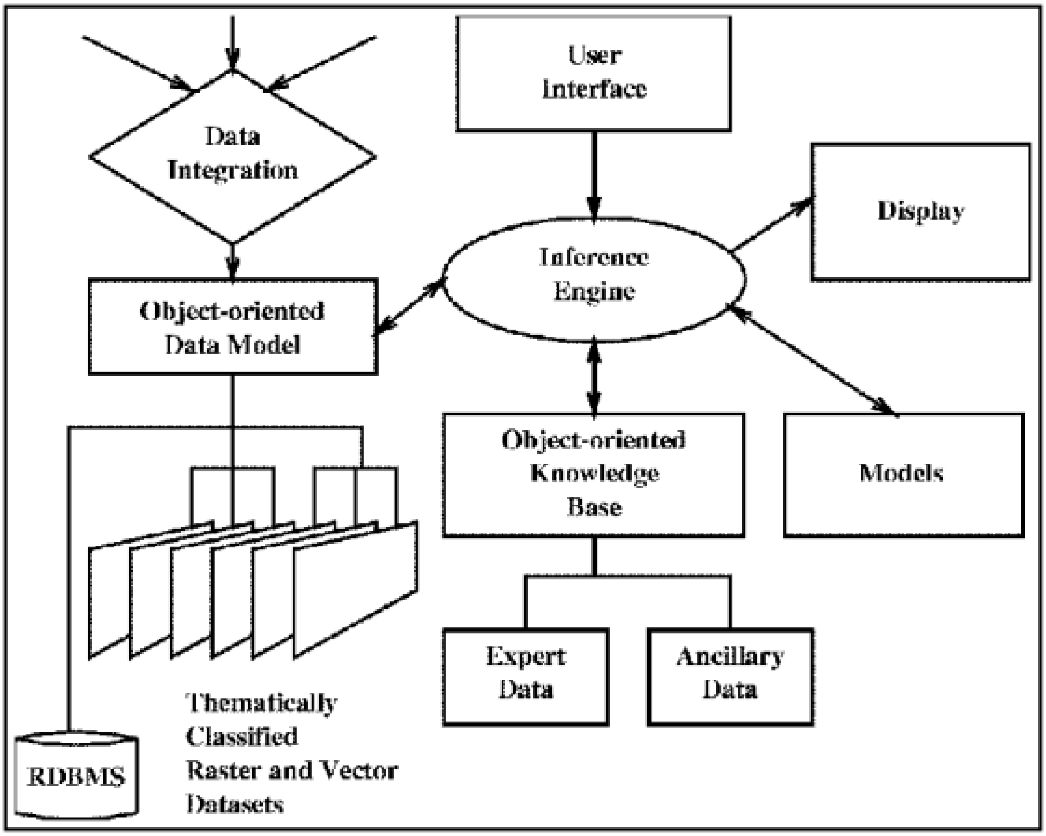


***Fig. 5:*** *The configuration of COAMES (from Moore et al 1996)*

superclass, such as a 2D-array data structure. In a further capability of object oriented structure, objects can be seen as communicating with other objects by passing messages that they can either accept or reject. As will be seen later, this is particularly useful for knowledge representation (Tello 1989).

### 3.2.2 Inference

From an initial user input (e.g. track movement of upper beach within an ord from time T1 to T2 at place P1), a very primitive natural language process extracts words based on comparison with the contents of all the subclasses under class 'Terms' to gain coast-specific terms ('shingle', 'beach' etc), context terms ('next to', 'in' etc), temporal-specific terms ('GMT', 'low tide' etc) and landform names. Certain words (e.g. 'ord') are used to trigger or invoke a set of knowledge, in this case based on the topology between beach features held in Figure 2. The specific set of rules and facts that comprise this knowledge is itself arranged in a hierarchical object fashion. This tree is descended through a forward chaining process, initially to restrict the operation of rules to those covered by the user's query (effectively training the hierarchy for ground control point processing). For instance, the first condition asks if the user's query is concerned with cliffs. If so, then that condition is flagged 'true', which is noted by the inference engine. Subsequently, the inference engine uses information encapsulated within the original object rule to point to the appropriate object in the next tier in the hierarchy, which is to look for evidence that the cliff is steep. Also encapsulated in the rule structure is a report, which is different for each outcome as dictated by the inference engine. For instance, having ascertained that the user's query concerned cliffs, the report corresponding to 'true' would be printed out to the user: "At the base of a cliff..is it steep?" A steep cliff would indicate the edge of an ex-

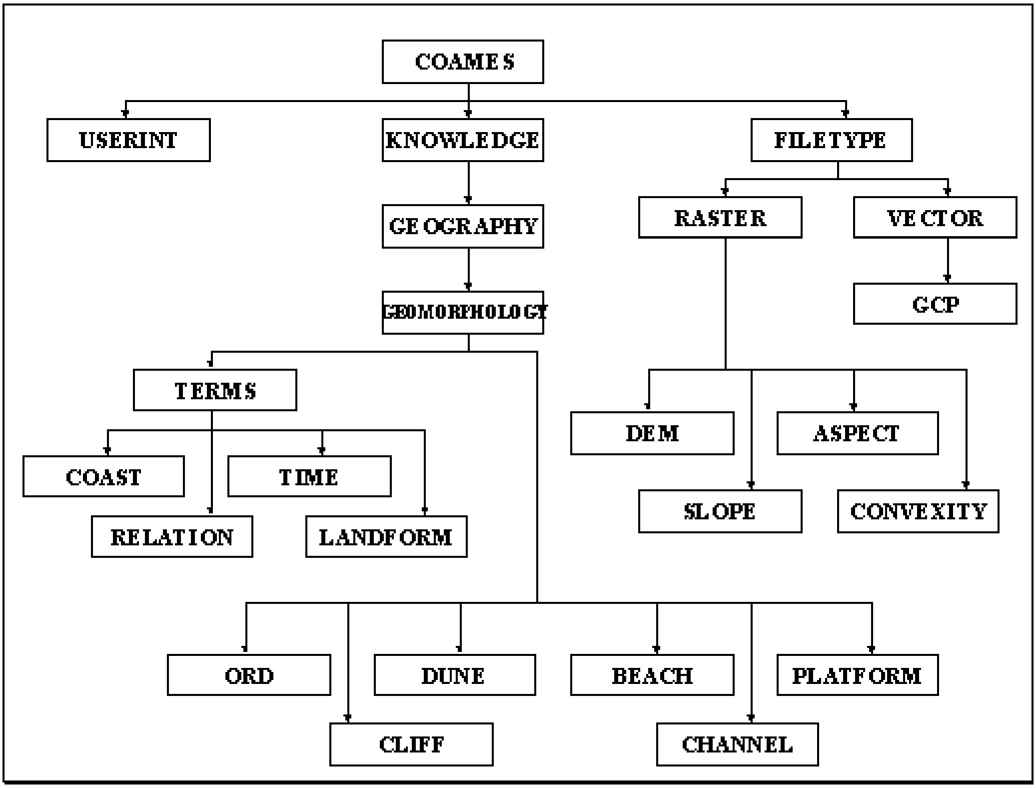


***Fig.6:*** *The object-oriented hierarchical structure of knowledge and data in the COAMES prototype*

posed till platform, though if there is no evidence to suggest this then the inference engine would point towards a stable (and lower-angled) cliff rule. This would indicate protection from the upper beach. Again, the applicable condition is marked 'true'. After fully descending the hierarchy, the process is repeated with ground control point data (each xyz GPS point surveyed has associated topological information that further defines its position), though movement is restricted to the flagged areas. If the ground control point meets the criteria defined by the user's original query (i.e. if it in some way defines the feature to be isolated), then the associated co-ordinates are stored and used to define a region with the help of a function encapsulated in the geography class. Used in this way, the ground control points can be seen to be intelligent. Within this zoomed in region, morphometric measures (Evans, 1972; Wood, 1997) encapsulated in the geomorphology class are used to isolate the feature more specifically by using the appropriate thresholds of altitude, slope, aspect and convexity for particular land forms. These thresholds are held in the same rule structures described above within unique morphometric rule hierarchies. The result of this can be seen in Figure 7.

What must be stressed about this object-oriented expert system is that the inference method is kept separate from the knowledge base. Traditionally, the knowledge base has manifested itself as a long series of IF-THEN statements where action is taken if a certain condition is met. This exhaustive approach results in the knowledge base and inference engine being closely entwined (i.e. the action is the task of the inference engine). Ideally, the knowledge base should not be so 'hard-wired' into the system, as it may need to be modified to meet specific demands. This is best done as a separate entity (Moore *et al* 1996).

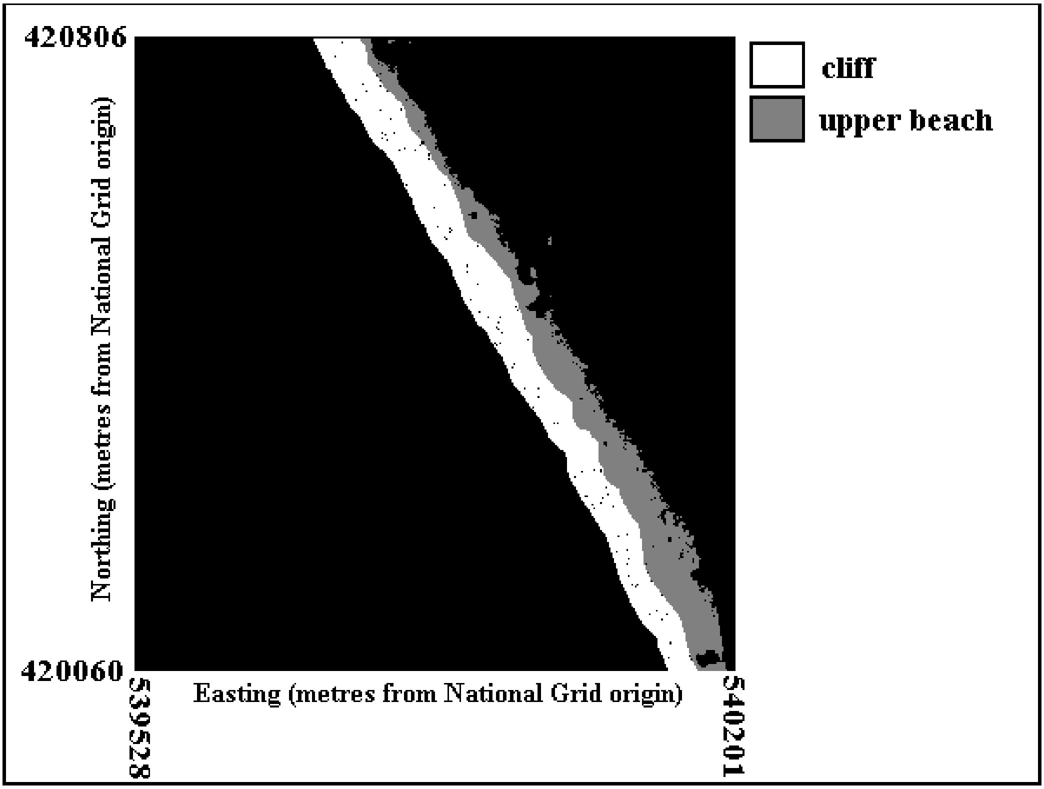


***Fig.7:*** *The isolation and extraction of the cliff and the upper beach from the study area on the basis of intelligent ground control points and morphometric parameters driven by the COAMES expert system*

## 5. Discussion

### 5.1 Error and uncertainty

With a coastal zone management system and indeed any expert system in a commercial or academic environment, users will need to know how much confidence to attach to any output and where the confidence limits may lie. No decision made will blindly rely upon output from this expert system. Therefore, incorporation of error analysis is extremely important in COAMES' structure. Burrough (1986) identifies three broad groups of error source, which were discussed with reference to COAMES in Moore *et al* (1996). In the case of rules, for example, there is a great deal of uncertainty in defining morphometric thresholds. It would be easy enough to say that upper beaches have a slope of between 3 and 6 metres, though there are cases that fall outside this. This potential error needs to be represented in the system. It follows that some measure of the quality of results is essential for the future development of COAMES. There are a few economic and practical reasons for this (Burrough, 1992; Miller & Morrice, 1991; Moon & So, 1995). The most common error modelling methods include Bayes' Theorem (a probabilistic approach, calculating uncertainty about the likelihood of a particular event occurring, given a piece of evidence – Srinivasan & Richards, 1993; Moon & So, 1995; Skidmore et al 1996), Dempster-Schafer theory of belief functions (can be used where evidence is lacking, embodying the representation of ignorance in probability theory - Scheerer, 1993; Moon & So, 1995; Ferrier & Wadge 1997) and fuzzy logic – Zhu et al 1996, Ferrier & Wadge 1997). Fuzzy logic has been used extensively for the processing of non-crisp terms such as 'good', 'fair' and 'poor' (see Brimicombe's (1996) work with linguistic hedges). This method is potentially valuable for further development of this prototype in the processing of user queries and the quantifying of terms such as 'steep' and 'stable' cliff.

### 5.2 Modelling Paradigms

It is worth considering how time and space is modelled. Raper and Livingstone (1995) propose modelling within a space-time paradigm, or in relative space (4D). It is a spiral model where since return of a flux is not to the same time, it cannot be to the same place. The conventional GIS method is to have time slices based in 'absolute space'. An example of absolute space is a design where events affecting objects create 'versioned objects' so that temporally different versions of the same object can exist. (Wachowicz & Healey 1994). The relative space way of modelling can facilitate the execution of theories about relationships between 4D space-time phenomena as well as spatio-temporal interpolation.

### 5.3 Other Considerations

Wood (1997) divided the methods of DEM analysis into extraction and also *a priori* means. Within this group, data sources such as classified aerial photography could be used as the isolation means instead of extraction methods. Moore *et al* (1996) investigated interfacing to models from COAMES (with specific reference to nutrient exchange through a coupled pair of models). For this geomorphological prototype, the results could be input into a cliff erosion model, aiding forecasts of erosion, which itself could be linked with the important sociological element of coastal zone management (loss of valuable land).

## 5. Conclusion

This paper describes the development of a prototype version of COAMES, which represents a pioneering application of expert systems to coastal zone management. In the philosophy of COAMES, this prototype study is seen as a building block that can be added to; this is allowed by the existing formulation of the surrounding infrastructure as specified by Moore *et al* (1996) in Figure 5. Now that this initial step has been made, subsequent efforts will include the investigation of temporal and spatial change relating to a feature and linking the findings with explanatory data (e.g. wave data, suspended sediment data etc.). An incorporation of error and uncertainty is of high priority due to the need to establish the validity of the system. To be an effective coastal zone management expert system, it is important to bring in sociological and legislative knowledge. Ultimately for this prototype, though, the consideration of the ord landform as a whole is an issue, as a means of testing the expert system's ability to prove or disprove the theory.


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