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Environmental modelling: issues and discussion

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12.1 INTRODUCTION

In this final chapter, problems related to the successful use of GIS and RS in the domain of environmental modelling are discussed. The basis for this discussion was a joint problem analysis by the participants and lecturers of the ITC workshop on 'Environmental modelling using GIS and remote sensing' using a so-called meta-plan procedure (please see the Preface for names and affiliations of participants and lecturers). Before presenting the joint problem analysis, a generic framework for dealing with geo-related questions in environmental management was presented to the participants. The results from the joint problem analysis are discussed below.

12.2 GEO-INFORMATION RELATED QUESTIONS IN ENVIRONMENTAL MANAGEMENT

Environmental management, generally, requires three different kinds of information. Firstly, the status of particular environmental indicators or variables must be estimated. For instance, where are the most polluted sites? Where are the most and least productive soils? What is the land use in a region? Such *'what is where'* questions are answered by individual surveys or observations; globally, the number of these surveys are enormous.

The second type of geo-information of interest to researchers and land managers is change over time. Typical questions may include: what is the change of the forested area in southeast Asia? How many hectares of agricultural land were abandoned in western Europe since 1990? What is the change in air pollution in the United States in the last 10 years? The *'what is changing where'* questions are answered by multiple observations over a time period. Such monitoring may involve periodically recording certain parameters at selected spots, or, if one is interested in area changes, a full survey at regular time intervals may be necessary.

Thirdly, managers are interested in projections, both spatially and temporally; such projections may be characterized by *'what will be where'* questions. For example: what will happen with the environmental pollution if we implement measure A? What will be the effect of urbanization on nature development in densely populated areas? Of the three types of questions, the *'what will be where'* type is most difficult to answer. Besides an initial state of the land use (the *'what is where'* question), an understanding of the process of change as well as the interaction between factors is required. This is extremely difficult, especially when biophysical and social-economical processes are considered together. In practice we see that it impossible to answer the question *'what will be where'* with great precision. Instead of a crisp prediction, we see the development of scenario's that represents possible lines of development.

In Table 12.1 the requirements in terms of data and processes of the three types of questions are indicated.

Table 12.1: Requirements for different questions.

Question	Data	Models	Techniques
What is where?	Spatial data	Model for spatial data	Standard DBMS and GIS
What is changing where?	Spatial data at time intervals	Model for space-time data	Standard DBMS and GIS
What will be where?	Spatial data at time intervals	Model for space-time data Model for projection	GIS, modelling environments and frameworks

Geo-spatial tools required for the analyses in Table 12.1 may be defined. For example, the *'what is where'* question requires a geographic information system (GIS) to store spatial data and make simple (Boolean) enquiries. The main constraints with this type of analysis lie in the domain of data access and data accuracy. For the *'what is changed where'* questions, multiple observations of land cover are required. Remote sensing techniques seem attractive for monitoring, but inaccurate classification, especially when compounded over time, may lead to unacceptably low accuracies. The analysis techniques available in GIS for analyzing spatial time series are also limited (Bregt and Bulens 1998). Methods need to be developed to survey, manage and analyze spatial data over time. Finally, for the *'what will be where'* questions, a combination of data, representing the initial status, and some rules or models describing the change of the environment over time, are needed. These rules range from relatively simple expert tables describing change in discrete intervals over time to complex dynamic simulation models describing change at continuous time intervals (see Chapter 2). It should be noted that the more complex dynamic simulation models are usually deductive, for example describing physical or chemical processes, such as the transport of water or the acidification of the soil (see Chapters 2 and 9). For exploring the *'what will be where'* question, data and transformation rules are combined in what is often called a spatial decision support system (SDSS) (see also Chapter 11). These systems generally consist of a standard GIS with some additional software components to facilitate decision support.

12.3 PROBLEMS RAISED BY THE PARTICIPANTS

At the end of the course, participants and lecturers discussed problems encountered in the practice of environmental management using GIS and remote sensing. This discussion was structured using a so-called meta-plan procedure. According to this procedure all the participants were asked to write, on separate pieces of paper, problems related to the topic of the course. Subsequently, all the problems raised were discussed and grouped into four main categories. In total 56 problems were mentioned. In Table 12.2 the main categories are presented.

Table 12.2: Main problems in the field of environmental modelling.

Main problem	Times mentioned	Percentage
Data	27	48
Modelling	13	23
GIS and RS technology	10	18
Expertise	6	11

Participants mentioned the issue of data for environmental modelling as being most problematic (see Chapters 3 and 4). The technology and the lack of expertise are considered to be minor problems, perhaps indicating that the technology and the development of appropriate skills are reaching a stage of maturity. Let us now have a closer look at the issues within the main problem categories.

12.3.1 Data problems

Within the data problem category the following issues were mentioned (note that the number of responses for each issue is in brackets):

- Lack of data and gaps in data coverage (spatial and temporal) (8)
- Accuracy and error propagation (7)
- Data costs (3)
- Data incompatibility (2)
- Data sharing
- Lack of common format of data
- Data collection
- Implementation of remote sensing observations in models.

Many practical problems are encountered with data in GIS modelling. Firstly, there is a lack of data, while data sets (spatial and temporal) frequently have gaps. If data are available, then accuracy may be insufficient to answer questions. Secondly, the cost of data is high reflecting the fact that field observations and mapping are time consuming and therefore expensive. Thirdly, there is hardly any programme focused on the systematic collection of spatial data to monitor the earth system; this problem is compounded by data from different sources often being incompatible (e.g. different scales, different classification systems being used in legends etc.), a problem discussed in Chapter 8. Remote sensing observations cannot be directly used in models. To convert radiation intensities into relevant parameters requires additional research. In general, data are scattered, incomplete, of variable quality and poorly documented.

12.3.2 Modelling problems

Within the modelling problem category the following issues were mentioned during the meta-plan procedure:

- Merging of data; scaling problems (5)
- Validation of models (2)
- Models: not good enough
- Incorporation of dynamic models in GIS
- Schematization of the complex real world
- Too much modelling and too little analytical work
- Developing models.

The participants and lecturers have clearly considered modelling in its widest sense; both the modelling of dynamic spatial processes as well as data modelling *per se*. The modelling and integration of data collected at different scales is considered to be a most important problem (see also Section 12.3.1). The validation of models is mentioned twice – there is clearly overlap with the problem of the quality of input data mentioned in the data problem section above. It was felt that the models are still not good enough, for example in the areas of dynamic modelling and dealing with the real world. During the course, and this book, it is shown that environmental models are useful for scenario studies on the state of the environment, and numerous models have been demonstrated (for example, see Chapter 2). The correct use of models requires, however, high quality models, in-depth knowledge of the model(s) being used, as well as systematically collected input data.

12.3.3 GIS and remote sensing technology problems

Within the technology problem domain the following issues were mentioned:

- Handling of remote sensing images from new sensors (e.g. hyperspectral, high spatial resolution, radar) (4)
- Remote sensing image interpretation (3)
- User-friendly GIS and remote sensing packages and specific software tools (2).

There are commercial systems available for GIS and remote sensing image processing as well as low budget systems with a remarkable functionality. Nevertheless, remote sensing image processing still requires specific software and hardware to be able to process data over large areas and to handle the new types of remote sensing data (see Chapter 3). The participants felt that remote sensing image interpretation is still a problem; this perhaps partly reflects the fact that the course focussed on GIS modelling, and not remote sensing *per se*. However, it is clear that the software for handling remote sensing images requires specific knowledge and is perceived as not being user-friendly.

12.3.4 Expertise problems

Within the expertise problem domain the following issues were mentioned:

- Integrated knowledge about GIS, RS and modelling
- GIS/RS; too far from user
- Cross-disciplinary work
- Practical know-how
- Lack of expertise
- Lack of trained persons.

Within the broad problem field of 'expertise', no single issue emerged. Topics mentioned may be broadly grouped as how to combine GIS and remote sensing technologies, enable inter-disciplinary work, and overcome a shortage of expertise.

12.4 PROPOSED SOLUTIONS FOR PROBLEMS BY PARTICIPANTS

The participants were then asked to indicate solutions for the problems mentioned in Section 12.3. The same procedure was followed: individual solutions written on paper were submitted to the session coordinators, and this was followed by a discussion among the participants and lecturers.

In total, 30 solutions were suggested. In Table 12.3, the groupings under the main problem categories are presented. A new category (General) was added for solutions that did not apparently fall under one of the main problem categories.

Table 12.3: Number of solutions for the main problem categories.

Main problem	Number of solutions	Percentage
Data	15	50
Modelling	5	17
GIS and RS technology	3	10
Expertise	3	10
General	4	13

Most of the solutions presented by the participants were given for the data problem (50 per cent). Let us now have a closer look at the suggested solutions.

12.4.1 Data solutions

The following solutions were suggested for the data problem (note that the number of responses for each issue is in brackets):

- Improved spatial and temporal resolution of RS (4)
- Standardization of spatial data (2)
- Lower the cost of data (2)
- Global climate database
- Global data accessibility network
- Development of data infrastructures and metadata
- Data warehouse
- More databases
- Common data format
- More ground observations.

The number of satellite systems is increasing, especially with commercial operators entering the market (see Chapter 3). The participants and lecturers expected high resolution imagery to be most useful for environmental modelling. Most of the other solutions suggest improved methods to store and distribute spatial data, for instance by using standardized databases that are easily accessible via the Internet. The development of spatial data infrastructures and easy accessible (global) spatial databases at low cost were considered to be the main solutions for the data problem.

12.4.2 Modelling solutions

The participants and lecturers suggested that the following ideas and developments would assist in solving some of the problems inherent in models:

- Better translation of models to applications
- More focussed models which deal with specific applications
- Development of new models
- Improved image processing models to insert remote sensing data into GIS
- Increased use of GIS in environmental and resource modelling and planning.

In summary, it was felt models that are better focused towards specific applications are required, both in the area of GIS as well as remote sensing.

12.4.3 GIS and RS technology solutions

It was noted above (Section 12.3.3) that technology was not considered a major constraint by the participants and lecturers. Indeed, the focus was on the integration of data from new remote sensing systems into GIS models. The following two points were made by the course participants

- More research on remote sensing data quality improvement (2)
- New sensors.

Solutions were expected from the use of new sensors and further research in the field of remote sensing data quality. Surprisingly, no solutions were mentioned in the field of faster hardware, though better software was implicit in the comments for improved modelling solutions. Apparently, the current GIS and remote sensing technology is fast and user-friendly enough to support users.

12.4.4 Expertise solutions

The following solutions were suggested to relieve the expertise problem:

- More GIS and remote sensing education
- Practical courses in GIS and RS
- Inter-disciplinary work.

A simple conclusion is that the main solution to the expertise problem is education, with an emphasis on a multi-disciplinary approach.

12.4.5 General solutions

We grouped the following solutions presented by the participants and lecturers under a 'general' category as no consistent theme was apparent:

- Increased public awareness
- Development of applications with users
- Better products for end users
- Mobile GIS/RS/GPS systems (hand-held).

Perhaps the general solutions can be best summarized as improved communication. The communication with end users and the general public was considered an important missing element in GIS modelling. The need to develop portable mobile systems may also be perceived as a solution to the communication problem.

12.5 REFLECTION

Perhaps the most interesting result is that the problems perceived with GIS modelling for environmental applications, that is data and models, has not changed in the last decade. At the First International Conference on Integrating GIS and Environmental Modelling held in Boulder Colorado, during September 1991, a similar list of problems emerged (Crane and Goodchild 1993). This summary highlighted systems issues (i.e. open architecture for model development, as well as systems benchmarking), data issues, GIS tools issues (i.e. tools fell short of what users require), and finally that a taxonomic catalogue of environmental models was required in order to better understand each model's value and its ability to interface with GIS (Crane and Goodchild 1993). In contrast, 15 years ago the main problem perceived in implementing GIS was hardware (Croswell and Clark 1988).

The lack of progress could be because our scientific knowledge of the Earth system accumulates at an agonizingly slow pace (Crane and Goodchild 1993), or perhaps it is because as human nature strives for knowledge, the perception is that progress is glacial. Certainly there is continuing progress in many areas of GIS applied to environmental modelling. We hope this book contributes in a small way to knowledge, and stimulates further research, demonstration and operation of GIS for environmental modelling.

12.6 REFERENCES

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