Ann Reg Sci (1992) 26:53–66

The Annals of
Regional Science

Geographical information systems and dynamic modelling

Potentials of a new approach

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Abstract. Combinations of dynamic models and Geographical Information Systems (GIS) have a vast potential to solve problems. Deficiencies and advantages of GIS and dynamic models are described. A multifaceted description of complex systems allows three different types of combining dynamic models and GIS. Different classes of dynamic models are used within these combinations. These are: – complex aggregated dynamic feedback models (e.g. like those of Odum, Forrester or of the AEAM work[1]), – simple generic dynamic models (in particular object oriented models) – models of physics based on partial differential equations (e.g. those for heat conduction or dispersal of noise or transport of gaseous pollutants). The model dynamics are combined with GIS held "base maps" to produce time series of maps, so called "Dynamic Maps". Base maps combine spatial features which are locally important for the dynamic process and are used to either modify or even form the dynamics. Different types of models need different types of GIS-held base maps and are adequate for different types of problems. This paper is based on a number of actual applications of one of these combinations; an overview is provided on potential applications of the whole new approach.

1. Geographical information systems

Geographical information systems (GIS) have become very important for storing evaluating, depicting, updating and processing of spatial data.

There are two types of representation of spatial data in the computer: the raster and the polygon format. Maps usually have the form of many different shapes, that is, of polygons. Most remote sensing data have the form of raster data. Many GIS's now offer the possibility to process both, raster and polygon data and to convert one format into the other. A good GIS allows to store the

[1] e.g. Odum 1982; Forrester 1968; Essa 1982.

topology of spatial relationships, i.e. which polygon is adjacent to which others, adjacent to which line features (line features: rivers, power lines, telephone networks etc.) and so on.

Updating of data is easier with GIS once the initial spatial information has been entered into the GIS. One of the most important features of GIS is the so-called map overlay: here different thematic maps are combined as if they were drawn on transparencies and a new map showing the intersections of all lines is generated. This feature is needed, when for example the ecological suitability of an area for a forest is evaluated. All spatial factors that are relevant for the growth of the forest are combined, as e.g. a map on the soil, a map on orography (altitude, slope, aspect), a map on soil moisture etc. All spatial features are about the same within each polygon of this new map generated through overlay of these thematic maps. Maps generated through overlay show the intersection of the different maps from which they are combined. They have many more polygons than the original maps or more information is available in each raster. Such overlay map can be used to assess the combined information, e.g. with respect to ecological suitability for a species or the suitability of areas in a region for infrastructural construction because all the combined information is additionally offered in a data bank attributed to the overlay map.

The results of evaluations with GIS can be shown in many different formats, e.g. as statistics or as maps. Maps are a very good means of communicating results as people have a unique capability to understand patterns.

GIS have a multitude of other features, which together allow a comprehensive and sophisticated use and processing of spatial data (Ashdown and Schaller 1990).

The details in the map do *not* represent the reality. The data are only a "*model of reality*", what is called the "data model" in GIS terminology.

- The boundaries between polygons are actually transition zones.
- homogeneous polygons are actually heterogeneous. There is an underlying continuous reality which is overlaid with a grid or a system of polygons. (These two examples are stressed by Goodchild 1991.)
- Although the definition where one spatial type ends and another begins is often somewhat arbitrary the resulting map looks unambiguous.

Other disadvantages:

- the collection of digital data is expensive and time consuming
- GIS data are more or less static
- the same numbers often have different meanings in different locations (e.g. in a case study it was found that a mountainous sub species of spruce naturally had downward bend needles whereas this "lametta syndrome" was one of the early symptoms of tree damage in other locations)
- the use of GIS needs specialized long training.

2. Dynamic models

Dynamic models depict complex structures and help to evaluate its inherent dynamics. Many different types of dynamic models exist to meet the manifold requirements for dealing with structures and their dynamics. A few examples are: feedback models (e.g. of the type developed by J. Forrester, H. Odum, or the AEAM group), Input/Output models, dynamic general equilibrium models, dynamic linear optimization models etc.

Dynamic models allow a better understanding of complex relationships. Their structure can be communicated to achieve a common understanding within a research group. They may show unexpected behavior which also helps in understanding problems. Some types of models tend to correct mistakes in data, in particular feedback models.

New insights in nonlinear dynamics have demonstrated that even some simple systems (Lorenz 1963; May 1974; Haken 1978; or summarized in Gleick 1988) and almost all more complex systems can exhibit unpredictable behavior. Whereas this inherent unpredictability cannot be overcome, the so to speak normal, practical unpredictability from complexity will be diminished. The situation may be ambiguous in that respect that in some areas the claims for predictability have to be withdrawn but that predictions will become much more powerful and practical in other areas. It is difficult to know which predictions will be corrected and to what degree and which predictions will be wrong.

Dynamic feedback models have difficulties to process numerous details. Manifold software packages exist to run dynamic models. Therefore dynamic models come in all disguises; no common standard exist. Communication of researchers is seriously impeded by this fact.

Education in structural thinking and in model building is often not good or does not even exist (nearly no university offers courses).

Models are often cross disciplinary. Specialized scientists tend to reject the transgression into their area by a model building group. They tend to defend their turf; modelers tend to underestimate the value of the knowledge available in the specific fields.

These factors limit the applicability and usefulness of dynamic models and impede the possibilities for training of systems people. As a consequence, models tend to be not nearly as good and useful as they could be.

Many dynamic models successfully process numerous spatial variables. But these are either structurally simple models, e.g. transport models of physics or they use structurally simple spatial data, e.g. geometrical grids. Models that are suitable to predict the future development of complex systems, in particular feedback models, are not adequate to process numerous spatial details. One reason valid for dynamic models based on difference equations: Here spatial details are depicted as state variables. Hence numerous spatial details lead to large scale systems. But large nonlinear systems of difference equations are theoretically capable of exhibiting whatever dynamics is desired. The general agreement here is that small models are useful and can be validated, large models are useless for prediction and not even good in supporting understanding of the system which was modelled. Already in 1973 Lee has written his "Requiem for Large Scale Models" (Lee 1973) where he as a user and developer utters his disappointment and frustration about the uselessness and total failure of large scale models.

An attempt to include spatial details into models would only be appropriate if the model environment also provides all capabilities of a GIS.

3. Reasons for combining geographical information systems and dynamic models

GIS data usually are voluminous. Some of the spatial information is static, e.g. orographical features, but other information is actually dynamic. It takes time and is expensive to update voluminous information. Therefore data in GIS tend to be static, although the dynamic information should be dynamic.

Some of the information, e.g. on soil types or microclimates, has been collected during years or even decades. Some data, e.g. several characteristics of microclimate, are long term average values. By definition it takes time to determine long term averages. Rapid updates are technically all but impossible for such types of information.

Hence GIS data are often crucially deviating from the real situation. Mechanisms or procedures are needed to achieve a faster "tracking" of the real situation by the data in the GIS.

Can remote sensing help in this more frequent update of GIS data? Remote sensing information can be converted into GIS formats. Some satellites submit their information quite frequently. Hence, remote sensing data is less static than information which was terrestically collected. But remote sensing data can only solve some of the problems of GIS data because remote sensing has other shortcomings. Some of these are: 1) not all terrestrial data can be observed with remote sensing, e.g. soil types. 2) Classification of new phenomena or of phenomena in unusual combinations is difficult and sometimes impossible. Terrestrial data collection and remote sensing are often complementary, not mutual substitutions.

Information produced by dynamic models is by its very nature dynamic. Could this information be used to try to anticipate the future development of spatial data? Again two reasons pose difficulties here: 1) multi-loop feedback models are inadequate to handle voluminous spatial data. 2) The availability of spatial data is uneven; in some areas many good data are available, while in others few data exist. Processing of uneven data in models is difficult.

But not only practical reasons limit the use of extensive spatial information in dynamic models. Theoretical considerations show that such an approach is inadequate. Therefore one of the authors has developed a multifaceted method to overcome some of the difficulties described here (e.g. Grossmann 1983 or 1991 a). In this method three different types of problems (or "facets") are seen in complex systems: – change of the structure; – dynamics generated by one particular structure; – and the details that are inherent in the structures and form them. Different methods are most suitable to tackle these different problems. GIS for example are often very good to process details, feedback models are adequate to model structures and to reveal the dynamics that are inherent in these structures. Therefore structures are evaluated with models; spatial data are processed with GIS. Each of these two facets of complex systems (complex structures and details) is processed with adequate methods. This multifaceted method allows to process details separately from the dynamic models and to combine the results of the different methods afterwards. The whole method is iterative.

The different types of dynamic maps described here are created by combinations between different types of models and different kinds and levels of details processed with the GIS (first results: Grossmann et al. 1984).

Models have some of the features needed to solve complex problems; GIS have others. Therefore these two tools are combined to allow more adequate solutions to such problems.

Three *different types of combinations of dynamic models with base maps*[2] exist, depending on the class of model. These are:

- complex aggregated dynamic feedback models,
- the so to speak "classical" transport models of physics, depicted as partial differential equations,
- simple generic models.

The resulting three different combinations are adequate for different types of problems.

4. Connection of aggregated dynamic models and base assessment maps

Many problems exhibit complex structures and aggregated characteristics. Examples for complex structures are 1): the relationships between demand for land, suitability of land for a purpose and resulting land use change, 2): the manifold factors in the preservation of bio diversity, or 3): the global structures involved in weather, climate and climate change.

Such structures can adequately be depicted with aggregated dynamic feedback models. Often the dynamics are similar through large regions, e.g. due to national laws or in continental build up of ozone during high pressure regimes. In the extreme such spatially extended variables can be global, as for example in the CO_2 increase. But locally the dynamics are *modified* by spatially varying factors, e.g. altitude, steepness, soil type, by administrative regulations or by the vegetational changes in the case of the CO_2 increase.

Therefore a dynamic model is used to produce time series describing such spatially extended variables. These numeric values are afterwards locally *modified* using a base assessment map generated with a Geographical Information System. The base assessment map (BAM) depicts the spatial distribution of factors important for the local modification. It could e.g. be the suitability for agricultural use or the risk for plants to be affected by ozone or the net primary production. These local factors could either be shown as polygons within a map or as raster data. The spatially extended dynamic variables are modelled only once in this method, using one central model, not within each polygon separately, as would be the case in the method of the "active area dynamics", see below.

The combination between the dynamics and the BAM is for example done as follows: the models specifies that an area of 0.5 km^2 will be converted from agriculture to forests in 1992. The BAM would in this case be generated in such a way as to depict the suitability for agricultural use. Those agricultural areas will be converted first that are the least suited for agriculture. Another example: if the conversion is intended for fixing CO_2, land which allows a high primary produc-

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[2] We differentiate between "Base Maps" and "Base Assessment Maps". Base maps are the general format of GIS data for combination with dynamics; base assessment maps are the special form of base maps necessary for the combination of base maps and *aggregated* dynamics.

tivity could be converted to forest use. In this way the definition of the BAM depends on the problem. The BAM usually depicts a polygon- or raster-wise assessment of a suitability or a risk.

The resulting map is plotted with the GIS in all these types of combinations between dynamics and areas. The locally modified values attributed to the polygons are plotted for all points over time, for which maps are desired. A feedback from the resulting maps to the model is possible but difficult.

Applications

Forest damage by pollutants[3]: The dynamic model contains the time series of emissions of important pollutants (precursors of ozone, i.e. volatile organic compounds, carbon monoxide and NO_x, sulphur dioxide) and the different scenarios how these will change in the future. The model describes the interactions between amount of biomass and resulting increased deposition caused by the vegetation and resulting concentrations of air pollutants. The BAM is based on the local distribution of the concentrations as modified by factors such as location of sources of pollutants, prevailing wind directions, exposure to pollutants, species and age of trees and resulting sensitivity to different types of pollutants and so on. Such a BAM is a risk map for the forests to be affected by forest damage. It does not show the actual amount of damage. The results of the dynamic model show the amount of damage, but not its location. This amount is distributed to the forest areas according to their respective risk to be affected. As models and BAMs differ with the hypothesis on the causes of the damage this method also allows the testing of hypotheses on forest damage. Different hypotheses lead to different maps which can be compared with the actual distribution of damage.

Tourism and its interactions with the regional economy and new agricultural strategies (see Haber 1985; Grossmann and Clemens-Schwartz 1985): Tourism needs specialized infrastructure. Therefore a region which would be attractive for tourists (due to climate, natural environment and location) has many more visitors, if such an infrastructure exists. However, selective tourists tend to avoid an area, if the density of tourists exceeds what they tolerate. The dynamic model describes such a mechanism and the resulting deterioration of an area. Several different BAMs will be used: the first one depicts the suitability for construction of infrastructure. The second one assesses the attractiveness for tourists. Combination of these two depicts those areas where infrastructure is likely to be built and tourists are likely to reside. From this the first candidates for destruction of areas by tourism can be derived. The resulting spatial pattern reminds of an attack of locusts on an area.

Spatial classes

Spatial classes are an important concept in land-use change. Land area within one class but within different categories can be converted into each other. Two examples are provided:

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3 Reported in Grossmann 1991 b–d and Kopcsa and Grossmann 1991 or Grossmann and Schaller 1986.

a) Forest die-back: Areas with healthy forest can be transformed into areas with forest affected by damage. There exist in all five damage categories in the German classification scheme: category 1: healthy forest; category 2: slightly damaged forest (loss of needles between 10% and 25%), category 3: damaged forest (loss of needles between 25% and 60%), category 4: severely damaged forest (loss of needles higher than 60%) and category 5: dead or dying forest. Forest of each category could change into each other category (category 5 by either regrowth or afforestation). Therefore only one spatial class exists in this problem area.

b) Study on agricultural land-use changes: Different categories of land were differentiated in an agricultural study which could not be transformed into each other. The suitability for agricultural use depends on several criteria: – steepness of the area, – quality of the soil, – exposure of the area, – content of rocks, – elevation of the area. Agricultural area of the suitability class 5 is very poor, elevated rockly land with a low quality of the soils, suitability class 4 is somewhat less rocky, less elevated, more favorably exposed etc., suitability class 1 is flat lowland area with a good quality of the soils. These five types of land belong to different spatial classes because steep, elevated land cannot be converted into flat area with good soil.

Shortcomings

The method could use very detailed spatial information. But usually the preciseness of the available different variables and their scale differ considerably. The actual measurement may only be valid within a few or just one polygon. The changes calculated by the method in the individual polygons are not stored and cannot be used in the model because the model only deals with aggregates. Therefore after some time the results become imprecise or even wrong. Also, changing environmental factors can have very different local effects. This can locally change properties or even structures of subsystems. But again the data of separate polygons cannot feed back on the aggregated model. Therefore the results of the aggregated model can stray from the actual development.

Changes in the different polygons happen in different ways. Therefore average values are only correct for a short time span. Also average values usually are not appropriate for very heterogeneous systems. But the method is based on average behavior which is locally modified. A specific version of another model would be needed to predict the development in each specific polygons if polygons are different. This is described in Sect. 5. A summary of advantages and disadvantages of the different methods is given in Table 1.

Software tools

The DYS-ARC software allows to evaluate models and translate their dynamics into dynamic maps using a BAM. This software asks, which BAM to choose and which time series of data to read. Afterwards it asks for the points in time for which to make the maps, checks the times and then starts a GIS to produce the corresponding time series of maps. DYS-ARC can also process dynamics from

Table 1. Characteristics of methods to link space and time (Grossmann 1990)

Area of application	Typical applications
1. Anticipation/ forecasting	Planning, perception of dangers, early warning, test of scientific hypotheses.
2. Environmental monitoring	Improved understanding of remote sensing data. Environmental early wearning.
3. Economic early warning	Economic planning, support for political decision-making.
4. Land-use planning	Land-use planning: Cities, villages, regions, federal states. Planning of landscapes and green areas. Planning routes for high speed trains. Planning, also of investments, in the area of tourism, recreation and spare time.
5. Use of resources	Management of agricultural and forest areas. Development of pollution of aquatic systems over space and time. Calculation of production of drinking water and its quality. Development of forest damage. Management of non-renewable resources. Management of renewable resources (e.g. water).
6. Planning of investments (Planning of sites)	Changes of markets, regions, accessibility for traffic, connectivity within traffic net works.
7. Risk assessments	Routing of dangerous goods. Siting of waste disposal sites.
2. Environmental planning	Tasks in protection of nature, rehabilitation, clean-up, area-related planning.
9. Environmental impact assessment	Problems with waste dumps. Planning of construction. Planning of infrastructural investments.
10. Transport process	Maps on emissions and deposition. Monitoring and updating of these maps ("dynamic Kataster"). Spatial and temporal changes of water pollution. Environmental impact assessment.
11. Strategic management	Dynamic strategic management. Economic early warning.
12. Research	All of these applications and basic research.

sources other than models. DYS-ARC allows to handle problems with up to 99 different spatial classes.

5. Connection of models of physics and GIS

Many transport processes of physics can be described with partial differential equations, which are solved numerically. Examples are: – electromagnetic waves, – conduction of heat, – dispersal of pollutants, – flows of substances and gases, e.g. of groundwater, – propagation of noise.

One example are models on the transport of pollutants. Here so to speak "wave fronts" on the dispersal of a substance are calculated. The calculation proceeds along a grid which resembles a fishing net. Based on the values from two grid points a new value in the direction of the transport is calculated. In addition values from the boundary of the area are included for the calculation. This procedure gives a spatio-temporal development. This development is *modified* by geographical details from the GIS, e.g. hills. Hills become preferred areas of deposition of the pollutant, if they are located downwind.

Mathematically the same equations are used for each grid point but with the specific data from this grid point. Therefore the same model has to be applied up to millions of times, depending on the size of the grid, to derive spatio-temporal developments. This contrasts with aggregated models, which calculate all values for past and future points of time in one model run. The models used here are mathematically simple compared to aggregated models. Complexity enters as many grid points are connected.

Züger from the Austrian research center Seibersdorf has coupled a transport model of air pollutants with the Geographical Information System ARC/INFO. W. Flake from ESRI/Munich has connected a dispersal model of noise with ARC/INFO[4]. No software exists, which solves the problem of connection of transport models and GIS in general in the way DYS/ARC does for the connection of aggregated models and BAMs.

For advantages and disadvantages of this type of spatio-temporal modelling see Table 2.

6. Active area dynamics: The connection of generic models and GIS

Generic models describe simple situations in a prototypical way. They are applied to a specific situation by being provided with data from this application, usually stored in a data base. They are used in connection with maps, if the dynamics, which have to be calculated for the polygons and a base map are more complex than models of physics.

Many informations and attributes are valid throughout the whole area. But the limitations of this approach were mentioned in Sect. 2: locally changed properties of separate polygons cannot be evaluated by aggregated model. In such cases information exists which can only be exploited, if individualized models are used in each polygon separately.

Example: In the modelling of the phases of forest development the same generic model of forest development processes the data of each polygon of a base map. The base map will have comparatively few polygons, as usually not many different phases of forest development exist in an area. A base assessment map usually has many more polygons. (In a case study on forest damage the BAM of the Rosalia area of 600 ha consisted of 6000 polygons. But the Rosalia area has only 33 departments consisting of between one to five different age classes each, giving a total of 89 sub-departments. Therefore the base map for the active area dynam-

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4 Züger: Austrian Research Center Seibersdorf, A-2444 Seibersdorf, Austria. Flake: ESRI Germany, D-8051 Kranzberg, Ringstrasse.

ics would have 89 polygons). If the model is run for a period of 100 years, depicting the development of a forest area with mixed ages, then an average of 40% of the forest areas are cut within the first 40 years. It is no longer feasible to apply the method of aggregated dynamics to an area that has changed so considerably. But the development of these areas can be calculated individually with a generic model which runs in each polygon separately and is based on the individual data of each polygon.

As generic models in such applications calculate the development of each polygon individually, the development of each polygon is depicted by its own model object, so that its own dynamic becomes visible. The name "active area dynamics" derives from this method.

Adjacent polygons often are connected to each other by transport processes. Therefore some applications of active area dynamics periodically need an interim balancing calculation. The changes caused by altered vicinity conditions are calculated and the updated data for each polygon are stored back in the data base. These data will be used for the next step.

The query language has to meet tough requirement: It must be possible to regard each polygon as complete in itself, because there are as many individualized model objects as polygons. Therefore each polygon should be handled as one separate element. The query language must support abstractions and object behavior to meet these requirements. In addition query possibilities like in a relational data base language are needed: e.g. it must be possible to ask the software to depict all model objects that represent polygons between specified age classes or polygons with a specified degree of forest damage or any combination between such queries.

Possible applications

Study of the relationship between forests and precipitation. (*a*) Microclimatic processes directly affect only small areas, although they are able to influence extended regions. This may in particular be true for the evapotranspiration by forests and the resulting influence on rain fall. Some forests store water and release it during dryer periods. Also they evapotranspirate so that larger forest areas could increase precipitation downwind.

(*b*) Now growth of the vegetation is simulated with the method of active area dynamics. An overlay map depicting the ecological conditions of different sites in a larger area is used as a base map. An object oriented simple forest growth model is put on each polygon of the base map to simulate plant growth and evapotranspiration. The resulting evapotranspiration is passed on to a climate model and the change of precipitation, most likely an increase in rain, due to the development of the vegetation is calculated. The new rainfall patterns are in turn entered into the GIS to modify the base map of the ecological conditions of sites. As forests upwind grow or are planted, additional areas may become suitable for growth of forests.

(*c*) Forest growth is modelled on all areas including those just made suitable for forest growth. The new or modified forest areas in turn could increase precipitation still further downwind. By iteratively repeating this process it can be deter-

Table 2. Applications of dynamic maps (Grossmann 1990)

	Aggregated models	Transport models	Active area dynamics
Area of application	Depiction of spatially extended phenomena which are locally modified with Base Assessment Maps.	Transport processes which can be described with simple mathematical equations and which are modified by local GIS data.	Forecasting of somewhat more complex systems based on polygons where spatially extended phenomena can be neglected.
Effort	Effort was recently drastically reduced due to new modelling tools (STELLA, PC DYNAMO, SIMCON, DYS/ARC). Computational capacity of a larger PC suffices. Considerable effort for the determination of connections within models. Comparatively low demand for data.	Standard models for the about 11 types of transport processes. High to extremely high computational demand. High demands on data collection.	No standardized models. Suitable languages for modelling not well known. High demands on data collection of non-standard data. For many applications extremely high computational demand. Overview difficult which model brings which results.
Advantages	Flexible overall optimization. Model results often are very similar to past actual development. Structural equivalence of models and reality is possible.	Precise, often unique solution. Well established method. Characteristics of data are well known. Little difficulty in determining suitable model because standard procedure.	Supports research and management on diversity over space and time. May allow new form of land-use (complex land-use). Very flexible, but simple models.
Disadvantages	Requires specific knowledge and learning of connected thinking.	Models are extremely inflexible. Problems due to isolated particular areas.	Overall views usually cannot be derived with bottom-up procedures.

mined where forests are possible and of which type given the initial rainfall regimes in that area. This process might well influence climate in larger areas of regions or even continents (NRC 1990). The method of active area dynamics can help to determine the final potential vegetation patterns if rainfall is evaluated beginning at the coasts and repeating the calculation ever further downwind.

GIS supported agriculture for decreased environmental impact. The threat of leaching of nitrates into the ground water depends on several factors, e.g. soil type, nitrate content of the soil, soil structure, nutrient uptake by the plants or location of ground water layers. In this application a risk map is produced to depict the risk that nitrates can leach to the groundwater. This is overlaid with a map showing the availability of nitrates. An object oriented model on plant growth is combined with a map showing the ecological conditions of the site ("suitability map"). This model is additionally fed with climate data. The model is used to show the predicted growth of an agricultural species on the suitability map. The uptake and hence availability of nitrates is depending on the growth of the plants and the initial availability of nitrates. The object oriented model is put onto each specific polygon that differs from its neighbors with respect to ecological conditions or availability of nitrates. With this combination of an object oriented model and a suitability map the development of nitrate availability can be predicted and monitored with a few actual measurements.

This map on availability of nitrate is overlaid with the risk map on leaching of nitrate. The resulting map shows the actual, temporal risk of leaching of nitrates. This latter map could even be used to spatially control the application of nitrates.

In a similar fashion other dangerous substances could be modelled.

Shortcomings of the method of active area dynamics

Active area dynamics are much slower than aggregated dynamic models, as a small model is run for each polygon. If not only local, but in addition also spatially extended variables exist, these in addition have to be calculated for each polygon.

The generic models need more detailed information to achieve precise results than the aggregated models. It is possible that no sufficiently precise and complete information is available. As a consequence, the generic models would not be more precise than an aggregated dynamic model, they just would be slower.

In general the two types of dynamic maps cannot be compared because they use different kinds of information and are applied for different purposes. E.g. the BAM in the Rosalia area (mentioned above) would be far more precise than the map for the active area dynamics with 89 polygons, but the dynamics produced individually for these 89 polygons by the active area dynamics would be more correct than those from the aggregated model – as long, as no spatially extended factors enter. These factors could not be entered into the generic model, because it would make them fairly complex.

Software tools for active area dynamics

The connection of generic models and GIS is methodologically difficult, because the bookkeeping is complex, where the model has to get which data and where it achieves which results. The development of a suitable software is urgently necessary but the expenditure of work is very high. But this new software is now under development. This software has to some extent, as mentioned before, to link capabilities of a relational data base and a modelling environment.

7. Summary and outlook

As different types of dynamic models have different areas of applications and different advantages and disadvantages they can for some applications be linked. This further extends the already vast applicability of dynamic maps.

The different types of dynamic maps allow new possibilities:

- Improved classification of remote imagery (a remote image is taken at a specific time). Dynamic maps can be produced to show the same area at the same time as the remote imagery. The dynamic maps can be based on data from terrestrial observation. In that case the two descriptions of the area are based on different sources of information. Therefore a comparison of differences can help to classify the remote imagery. Very often the classification of remote imagery is a major problem, in particular if new or unexpected developments occur.
- Support for environmental monitoring. The expected development (from any vehicle of anticipation) is translated into dynamic maps and compared with the actual ongoing development (from terrestrial observation, false-color infrared photographs or remote imagery). Differences may reveal unexpected developments at a very early time. The differences may be evaluated with statistics and comparison of patterns.
- Maps for guiding and scheduling management actions in ecosystems (e.g. where to plant or harvest what at a specific time). In the most elaborated form, a complex multispecies plant-model is translated into maps for a specific plantation. These maps will support schemes of complex land-use (Haber 1979, 1985; Haber et al. 1984).
- Assessing the applicability of models. Finding errors in structures and data.
- Calibrate, (in-)validate or improve models. One data base (the data used for the dynamic model) is used for calibration. The dynamic model is then applied in the process of generating dynamic maps. The resulting maps can in turn be compared with reality. This allows additional procedures for validation or "invalidation".
- Update information in the GIS. This update is partially based on model predictions which will not always be valid but will in each case demonstrate where the fastest or most drastic changes are either expected or are likely to occur and where hence efforts for updating by actual observation should have priority. This allows to partially overcome the limitations with the nearly static character of spatial information in GIS.

The coupling between dynamics and spatial details is a translation process that exists in reality. Therefore it is much more than a mere trick to circumvent the limits of dynamic models or of GIS'. As the bulk of the information is kept in data banks the dynamic models are kept small. As a necessary and adequate consequence this coupling prevents large scale models from coming into existence. Each type of data is processed with those methods that are most adequate for this processing. The result, the dynamic maps, allow many new possibilities for validation.

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