The Forest Environmental Monitoring and Management System (FOREMMS) Project

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Abstract

The objective of the project is to develop and demonstrate a system and tools for trans-boundary environmental monitoring and management of forests in Europe. The system can be operated for monitoring at a regional, national or European level. It includes innovative approaches for retrieval of forest environmental variables from remote sensing data. The project will develop and demonstrate the system through a mini-network including three European countries spanning the main forest diversity in Europe. In the future, the solution should develop into a distributed monitoring system for the whole Europe. The whole-European network will contribute to a development towards a coherent international monitoring and management.

Introduction

The Forest Environmental Monitoring and Management System (FOREMMS) project is carried out by 11 partners from eight European countries. The Commission of European Communities supports the project, which is coordinated by the Norwegian Computing Center on behalf of the international team. The main goal in the FOREMMS project is to develop and demonstrate an advanced forest environmental information and management prototype system. The operational system will be able to monitor the whole Europe giving precise and coherent information on the environmental status and development of European forests over long time. The main data source to the system will be remote sensing data.

The project was initiated in 2000 by carrying out a survey to identify user needs for the FOREMMS system. The user needs analysis was performed by administering a questionnaire to potential users by post or by interview in different European countries or with EU organisations. Three main classes of user community were addressed – the general public, professional users and teachers. It was found that continuous monitoring of forest related variables is an important feature for the large majority of users, for example related to detecting trends and changes in forest health conditions and stress. Professional users are typically interested in variables such as tree species, age, stem volume, density, crown cover, height, health condition, diameter, biomass, and dead trees, in particular in the format of maps or and changes over time. Users were also attracted to the possibility of being able to move between maps at different spatial scales.

The project has then been through a system design phase and is currently within the system development phase. This includes development of remote sensing methodology and the IT components of the system. A first version of the prototype system will be implemented by the end of the year.

The FOREMMS system concept

The project will develop and demonstrate a system and tools for trans-boundary environmental monitoring and management of forests in Europe. The system can be operated for monitoring at a

regional, national or European level. The project will develop and demonstrate the system through a mini-network including the three European countries, Finland, Poland and Italy, spanning the main forest diversity in Europe. In the future, the solution should develop into a distributed monitoring system for the whole Europe (see Figure 1). The whole-European network will contribute to a development towards a coherent international monitoring and management. There will be participants from different parts of Europe ensuring that the contents and use of the system also will reflect the cultural diversity within EU. The FOREMMS system will handle monitoring at three levels. Each level is connected to a geographical area of some typical size:

- Level-1 areas of size about 20 km^2 that are wholly included in Level-2 areas
- Level-2 areas at 3,000-30,000 km^2 that are wholly included in Level-3 areas
- Level-3 areas, each of the same size as the whole area monitored by a FOREMMS node.

Figure 1. The FOREMMS operational network.

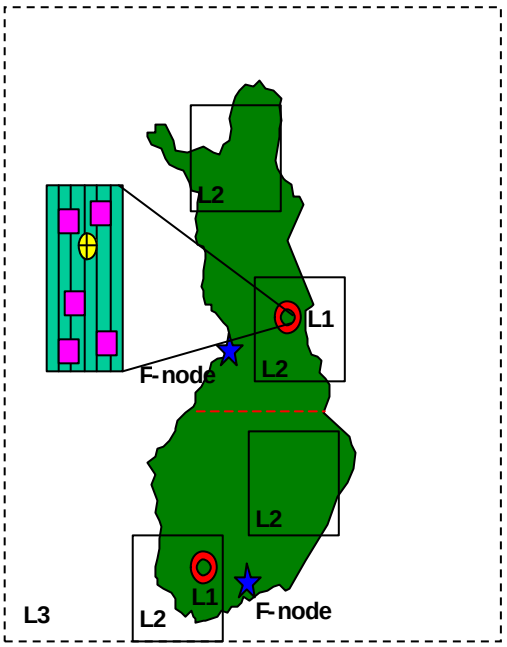

Figure 2. The three monitoring levels.

A FOREMMS node is a realisation of a single FOREMMS data processing and storage system. A node will typically have the responsibility of monitoring a geographical area corresponding to a country or a part of a country. The total number of nodes in Europe should cover the entire European geographical area. It shall be possible to retrieve information on the European level by contacting any of the FOREMMS nodes. Level-1 areas will be monitored by ground sensors providing point information and airborne sensors providing area information. Level-2 and Level-3 areas will be monitored by satellite sensors with different resolutions.

Figure 2 shows an example on how the nodes can be situated in one country, in this case Finland. Selected regions will be nominated as Level 2 areas for coverage by high-resolution satellites, typically Landsat TM. Some of the areas will be fixed, other will be selected by random in order to get good Level 2 coverage of the whole Europe over time. Level 2 areas can include one or several Level 1 areas selected for detailed monitoring by aircraft, automatic field stations and manual field measurements. Data will also be collected at European scale (Level 3, e.g. Terra-1 MODIS). One of the core topics and goals for the FOREMMS project is to deduct information valid for a certain level based on data recorded for another level. Advanced statistical models will be used to achieve this. This will allow cost effective high-level monitoring to become more useful in the future.

Figure 3 shows the overall conceptual model. The central module is the *Database Management System* for storage and handling of the forest environmental data for the specific total monitoring region at hand. Data are processed and delivered from three sub-systems covering different scales and sizes of monitoring areas. The *Level-1 Data Processing* sub-system receives data from automatic field monitoring stations (e.g., air pollution data), manual field measurements via a special field workstation with GPS, and airborne remote sensing as input. Standardised forest environmental parameters are extracted from these data sources and stored in the system database. The *Level-2 Data Processing* sub-system extracts the same parameters on medium scale from satellite imagery using Level-1 data from the local node areas for calibration of the classification methods and inversion models. The *Level-3 Data Processing* sub-system does correspondingly at large scale covering the whole monitoring region and using Level-2 data for calibration. Time series of data are analysed by the *Statistical Data Analysis* module in order to, e.g., determine trends in the temporal data sets. The presentation of the environmental forest parameters is the done by the *Use Case Handler*, which includes a web server. Advanced interactive visualisation makes it possible to study one or more parameters at the same time in 2-3 spatial dimensions and in the time dimension. The module produces standardised and tailored map products and statistical reports (graphs and tables).

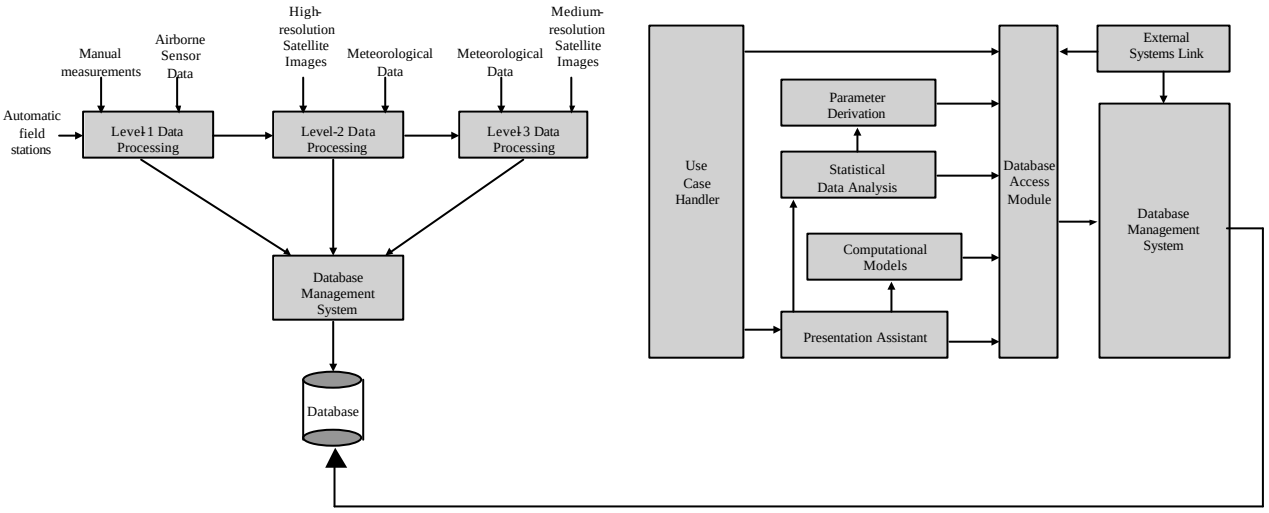

Figure 3. The FOREMMS system conceptual model.

Data analysis

The architecture of the system and the monitoring approach are innovative solutions. By the use of the three monitoring levels, it will be possible to use medium-resolution satellite data to monitor the whole Europe. The higher accuracy at the two other scales is used to configure the data analysis of the coarse-resolution data in order to be much more sensitive to the parameters sought than it would through the ordinary training and classification approach or calibration of an inversion model based on calibration parameters, which may be far from the "true" for the situation at hand. In particular, weather effects (e.g., presence of variable water contents on the canopy and in the atmosphere) may create large variability in the data measured, which is not related to the environmental state.

A new statistical approach is developed and applied for the propagation of information between the different spatial levels and to extend the information from Level 1 areas through the intermediate Level 2 to the whole Europe covered by coarse resolution, Level 3, remote sensing data (see also Høst et al. 1995). The approach is to establish empirical relationships between variables measured

at the various levels. This will provide tools to predict Level 1 properties from Level 2 data, and Level 2 properties from Level 3 data. As a result, this gives a complete link between variables at the spatial resolution of Level 3 to variables at the spatial scale of Level 1. Of particular concern in the establishment of statistical relationships are the quantification of what is lost in precision at the various transitions and aggregations, and the quantification of such loss in precision (uncertainty). The resulting statistical model enable the combination of all available information at all levels and ensure that proper weight is given to each data source.

Our modelling approach is based on a generalized linear mixed model, applied to space-time data and fitted into a dynamic multi-scale framework. This general statistical framework for multi-scale multi-sensor multi-temporal analysis of remote sensing data also allows for a variety of estimation procedures. The method seems capable of describing a wide variety of effects typically present in remote sensing data. Furthermore, our framework should be capable of describing a wide range of forest parameters with presumably different statistical properties. This is of particular relevance to the FOREMMS system, since the methodology should be applied to many different forest variables.

Conclusions

The success of FOREMMS depends upon achieving the following seven objectives:

- To develop a system that is in accordance with current and future user
- To monitor forest resources at the three scales regional, national and international
- To improve and integrate advanced remote sensing technology based on airborne and spaceborne sensors for the extraction of forest environmental parameters
- To advance techniques for multi-scale integration of information in order to improve large-scale coverage by scattered information from more detailed scales
- To develop techniques for the derivation of forest meta-data/higher-order information from spatial-temporal (4-D) collected data
- To contribute to the development of a standard scheme for European-scale collection and analysis of forest environmental parameters
- To prepare for the deployment of the system covering the total European forest resources

The FOREMMS project will have to reach all of these objectives to be able to develop an environmental monitoring and management system prototype that can be demonstrated at the three test sites. A successful demonstration will hopefully pave the way for the implementation of a comprehensive operational system across Europe for the benefit of the environment of our forests.

References

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