Web-based Information Systems: Data Monitoring, Analysis and Reporting for Measurements and Simulations

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Summary

This paper describes the concept, implementation and application of the Web-based Information System 'Turtle' for data monitoring, analysis, reporting and management in engineering projects. The system uses a generalised object-oriented approach for information modelling of physical state variables from measurements and simulations by sets of tensor objects and is implemented platform-independently as a Web application. This leads to a more flexible handling of measurement and simulation information in distributed and interdisciplinary engineering projects based on the concept of information sharing. The potential and advantages of Web-based information systems like 'Turtle' are described for one selected application example: a measurement programme dealing with the physical limnology of Lake Constance.

1 Introduction

Computing in civil and building engineering deals with one 'raw material' of the human society: information. Information is one important basic resource of engineering projects to adapt the natural environment by artificial infrastructure to satisfy the demands of the human society. Planning, design, and control of artificial infrastructure is based on a deep understanding of the natural environment such as physical, chemical and biological behaviour and the interaction with human interventions. This demands huge efforts on field observation and laboratory experiments as well as on computer-based simulations. Based on the progress in measurement techniques/instruments and of the simulation methods/tools all these activities lead to mass data and to new challenges for ICT-application: The computer and the network is not any more just a number/data crunching engine, it has become the standard tool for information management.

Modern measurement and simulation techniques allow suitable accuracy and density of data recording but also require a careful preparation, performance, analysis and archiving of field, laboratory or computer experiments. The results are mass data with respect to the different spatial and time dimensions and scales. On-line monitoring and pre-analysis during the application ensure the quality of the measurements and simulations. Post-analysis, detailed reporting and long-term archiving lead to a beneficial scientific and practical use of the resulting information in balance to the application efforts. All these demanding tasks and the mass data management require the application of a corresponding suitable information system. The term information for this purpose considers besides the conventional meaning of data also the corresponding functional properties (behaviour, analysis) as well as syntax and most important the semantics from the engineering point of view. This leads to a new importance of information modelling in civil engineering to apply modern techniques from computer science such as object-oriented modelling, Web-technology and XML strategies. The target is to apply this technical progress in a beneficial way for actual measurements and simulations as well as on a long-term view of information reuse and retrieval in information bases to integrate several existing information sources. This task is getting more and more important by the holistic, interdisciplinary view of the impact of artificial infrastructure and its impact on and interaction with the natural environment.

2 Web-based Information System Turtle

2.1 Information Modelling Prerequisites and Concept

Physical state variables as mass data differ much in type, dimension, and structure. Conventional information systems are specialised for the specific measurement/simulation techniques, sometimes using standard data bases. Usually, they do not combine data with functions and explicit semantic towards independent information units. Specific export filters and interfaces to analysis, visualisation, and documentation packages ensure data exchange to other tools or integration with other data sources. This leads to specialised software packages not designed for a platform-independent and net-based application in a heterogeneous environment.

Measurement and simulation data are usually used for scientific analysis or operational improvements by several experts from different institutions and disciplines in a heterogeneous computer environment. The applied analysis methods and related software tools differ in their internal data formats and in the support of external interfacing - an obstacle for trans-institutional and interdisciplinary collaboration. Most users do not have the time to develop and apply standardised formats or interfaces. This leads to several incompatible 'personal' versions of the 'valuable' data with a high amount of implicit information. Information exchange/sharing is restricted. In the long-term – based on the staff exchange – there is a loss of data, knowledge and experience. Application-independent information systems for monitoring, for long-term data analysis, reporting, and management as well as for interdisciplinary collaboration are rare.

Modern information and communication technology (such as OOM, XML, Web technology, distributed data bases) in combination with well-known engineering basics from mathematics (such as set and tensor theory) enable the introduction and application of flexible and platform-independent information systems as standard tools. They might reduce the implementation and application effort and increase the flexibility for net-based collaboration in heterogeneous, interdisciplinary, and distributed environments. Prerequisite is a generalised information modelling approach for relevant measurement and simulation data in combination with the corresponding semantic and functional/operational properties.

2.2 Tensor-based Information Modelling for Physical State Variables

The basic idea of 'Turtle' for information modelling of measurement and simulation data is the application of object-oriented modelling (OOM) by a generalised class family for sets of tensors. Objects and the corresponding classes describe semantic information units by attributes (data), methods/behaviour (internal functions), and operations (external interfaces). The application of object-oriented principles allows the setting up a powerful system-independent class family for component-oriented system development. This kind of information modelling can be easily applied to all application domains of civil engineering for physical state variables such as data from measurement programmes and software simulations.

As an example, physical state and behaviour variables for one- and two-dimensional physical processes can be structured by the dimension of the corresponding coordinate systems as scalars (coordinate independent variable), functions (variable depending on one coordinate) and fields (variable depending on two coordinates). More types of variables depending on three or more coordinates can be easily extended but will be not considered in this paper. The number and order of values is a second property to classify physical variables as units (one value), sets (several independent values) and vectors (sequential ordered values). These two classifications lead to nine tensor classes covering all typical kinds of data for one- and two-dimensional measurement and simulation models in civil engineering. Details of this concept are described in *Molkenthin (2000)*.

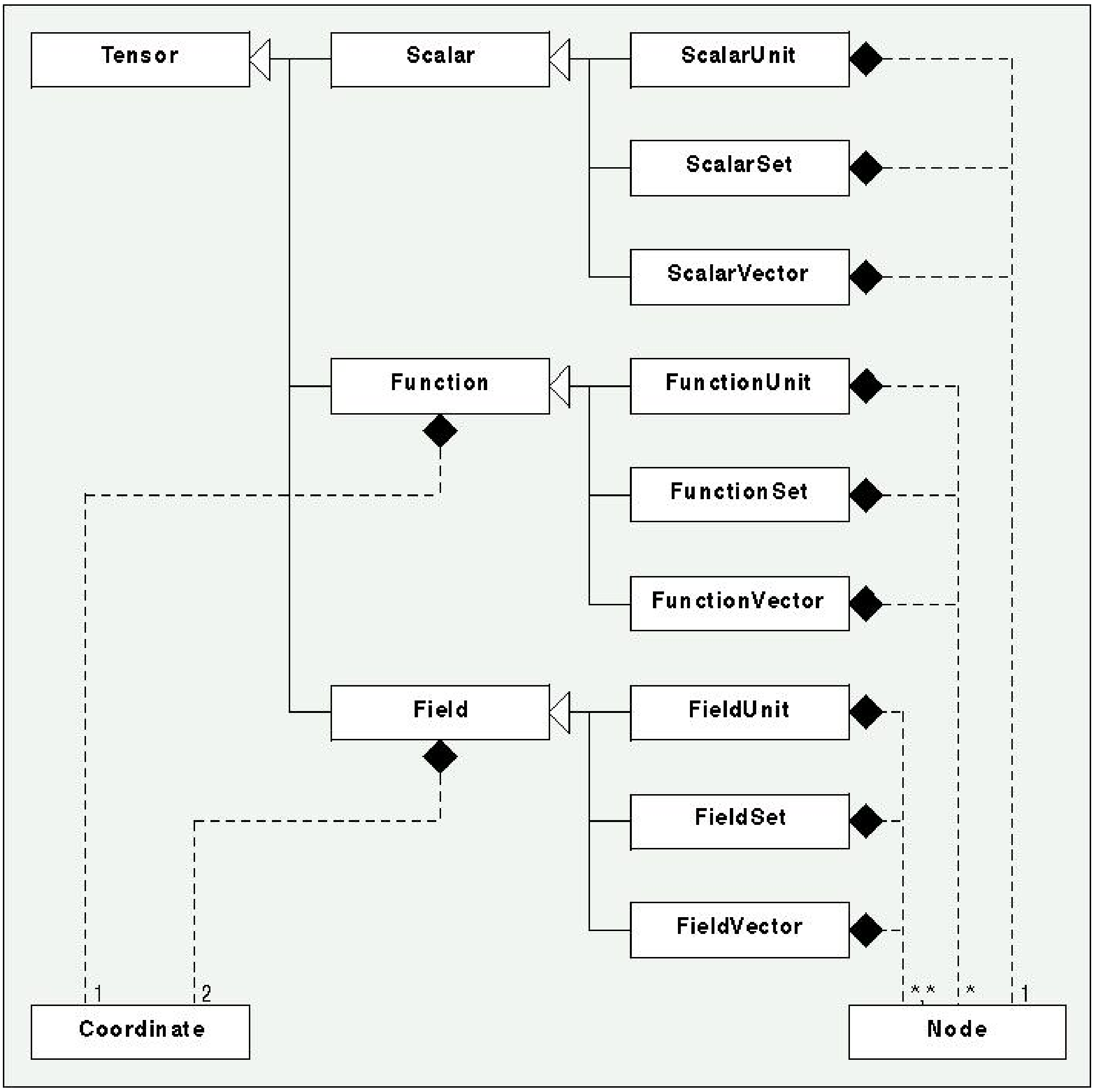

Figure 1: Tensor Class Concept

Measurement and simulation data can be easily described by these system-independent tensor classes with all attributes, methods such as standard analysis (integration, differentiation, extreme and mean values, griding) and related standard tools for user interfaces (forms, diagrams, tables and reports) as Web objects. The tensor classes and corresponding tensor tools form the core components of Web-based information systems for measurements and simulation. The set up of such a system is reduced to the modelling of the relevant measurement/simulation data by sets of tensor objects and the composition of the information system by standardised tensor tools and some few project specific tools. This approach of tensor-based information modelling in combination with the application of modern software engineering has been used to develop the information system 'Turtle' for civil engineering projects.

2.3 Implementation

The system has been implemented as a platform-independent and Web-based software using Java-technology. The general implementation effort for an information system is reduced significantly by reusing the generalised Java class packages for tensors and related user interface and reporting instruments. The system supports different application modes like stand-alone application, thin client mode (DHTML/Servlet), and fat client mode (Applet/Servlet) to support the application via Internet in distributed project environments.

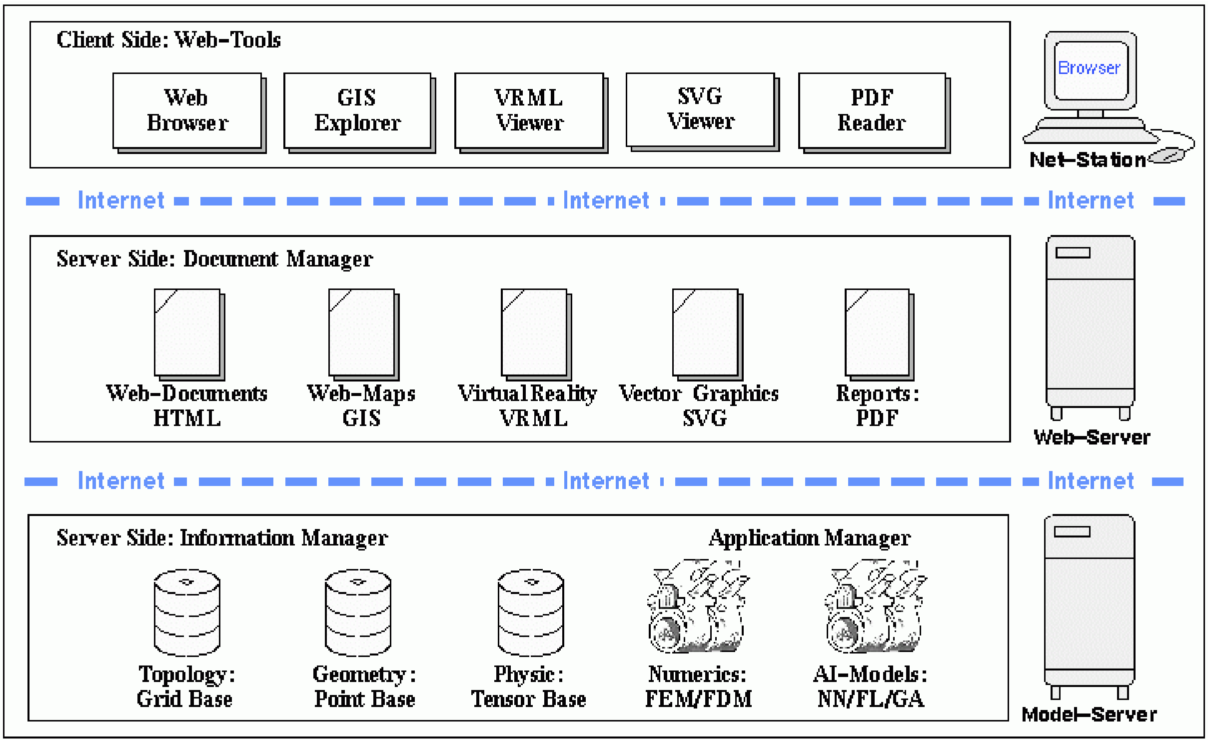

Figure 2: Technological Concept Web-based Information System

3 Application Examples

The Web-based Information System Turtle has been applied in several projects from education, research and practise. Based on the generalized approach typical application examples are:

- resource management: forecast in a call centre for construction waste disposal
- flood management: water level gauge information system for rivers
- simulation system: long-shore sediment transport simulation in coastal regions
- measurement programme: wind and internal waves measurement Lake Constance

In respect to the limitation of a conference contribution, this paper describes the application for the interdisciplinary measurement programmes Lake Constance 2001 and 2003. However, the experiences from the different application examples confirm the benefit of the simple but powerful modelling approach of Turtle by a generalized class family for sets of tensors.

4 Measurement Programme Lake Constance 2001 and 2003

4.1 Target and Partners

Lake Constance as one of the largest lakes in Central Europe has great importance as a unique ecosystem, drinking water storage, and as a basis for professional fisheries. The understanding of the movement of the water and the numerical modelling of its hydrodynamics are important steps towards a sound basis for future decisions of lake managers in order to ensure high water quality. The joint research project "Modelling of High-Frequency Internal Waves in Lakes" of the Institut für Wasserbau (IWS), Universität Stuttgart and the Centre for Water Research (CWR), University of Western Australia, partly funded by the DFG (German Research Foundation), deals with the modelling of groups of high-frequency internal waves in stratified lakes. Field measurement programmes in autumn 2001 and 2003 were part of this project and measured data serve as a basis for the validation of the existing simulation programme CWR-ELCOM (Estuary and Lake Computer Model) as well as for a better understanding of the generation of high-frequency waves in Lake Constance.

4.2 Measurement Concept and Data

Between 11 October and 17 November 2001 as well as 15 October and 27 October 2003 intensive measurements were carried out in Lake Constance. The objective was to measure the spatial and temporal wind field over the water surface (wind speed and direction), at the land side (by meteorological services) and the internal wave response of the lake from basin-scale internal waves down to high-frequency waves. Therefore, CWR Lake Diagnostic Systems (LDS) were installed at several fixed locations in Lake Constance.

The lake stations measured water temperatures at 51 points over a depth of about 100 m and wind speed and direction in 2.4 m height above the water surface. One lake station was additionally equipped with a weather station, measuring relative humidity, air temperature, incident short wave radiation, and net radiation. All sensors of the lake stations were generally sampling in 10 sec intervals in order to measure high-frequency internal waves. The wind stations at the shore operated by Swiss and German meteorological services provide their data in intervals of 10 min to 1 hour.

The lake stations were controlled by the already existing CWR LAKEMON software at the shore-based station, where data were collected at regular intervals of 1-4 hours via GSM mobile phone telemetry. The raw and converted data files were stored locally and after collecting 1 MB of data, sent to the CWR Field Operations Group in Australia, where the measured data were visualised with Matlab scripts and directly posted on a Web page. The same procedure war performed separately for the wind data from the meteorological services. Comparisons between lake and land wind data were not possible as the data were in different formats and on different time scales. This kind of data processing by sets of ASCII data files and pre- and post-processing tools is typical for measurement and simulation tools in civil engineering.

4.3 Application of Turtle

The Web-based information system Turtle was applied during the measurement programmes 2001 and 2003 for the pre-analysis and for reporting the whole data set. All field measurement data were modelled by the described tensor classes: the water temperature T(depth, time) as a scalar field, the wind speed and direction v,α(time) as a function set and air temperature, humidity, short wave radiation, and net radiation as a function unit for each of these variables. These tensors form a tensor set for each of the stations in the lake. All tensors were filled with the data by reading the different ASCII measurement files generated by the CWR LAKEMON software. The same was done for the wind data from the meteorological services using the same tensor classes as for the lake wind data.

The involved experts used different hardware components (notebook, desktop computer and server) with different operation systems (Linux, Windows) and different Web browser (Netscape, Mozilla, IE). The whole system was installed in this heterogeneous environment without any adaptation to the specific platform. The system has been applied for three important project steps: on-line monitoring during the experiment, pre-analysis, and information mining as input for simulation models afterwards as well as long-term reporting and archiving of the measurement results for later reuse. The functionality of 'Turtle' for these three application steps will be briefly described.

4.3.1 Application during the Measurement Programme

The main application of 'Turtle' during the measurement programme was the on-line check of data in order to detect technical problems and to get a first pre-analysis in respect to the physical behaviour of Lake Constance. The transmitted data files were automatically checked by 'Turtle' for gaps, transmission errors, calibration errors, and plausibility. HTML report pages were generated including key information (e.g. mean values), visualisation (function plots, isotherm plots, wind roses) as well as the whole data set on a Web server. All involved experts had always open or password-protected access to these on-line reports to observe the ongoing field measurement and to have an updated overview on the actual situation in the lake independent of their location. All necessary analysis and visualisation functionality for this service were applied by the tensor class methods without any special implementation effort.

4.3.2 Pre-Analysis

The pre-analysis functionality of 'Turtle' was used during and shortly after the measurement programme. Main feature for this purpose is the griding functionality to convert the originally measured tensor objects on different time interval scales interpolating gaps and decreasing the data density by mean values. Besides the 10 sec time step this feature was used for 600 sec (10 min), 3600 sec (1 hour) and 86400 sec (1 day). These additionally generated tensor sets allowed a flexible zooming between the different time scales to detect the high- and low-frequency behaviour of the lake. Corresponding Web objects (diagrams and generated DHTML pages) provided suitable user interface instruments for this important feature. Export interfaces (e.g. ASCII, Excel, Matlab formats) allowed to process pre-analysed data on the chosen time scale in other tools such as numerical simulation systems. The griding functionality was also used to compare the different wind data sources (lake stations and land stations) on the same level. In a scientific study these collection of wind data was used to develop an interpolation methods for the wind situation on the lake (Wagner 2003).

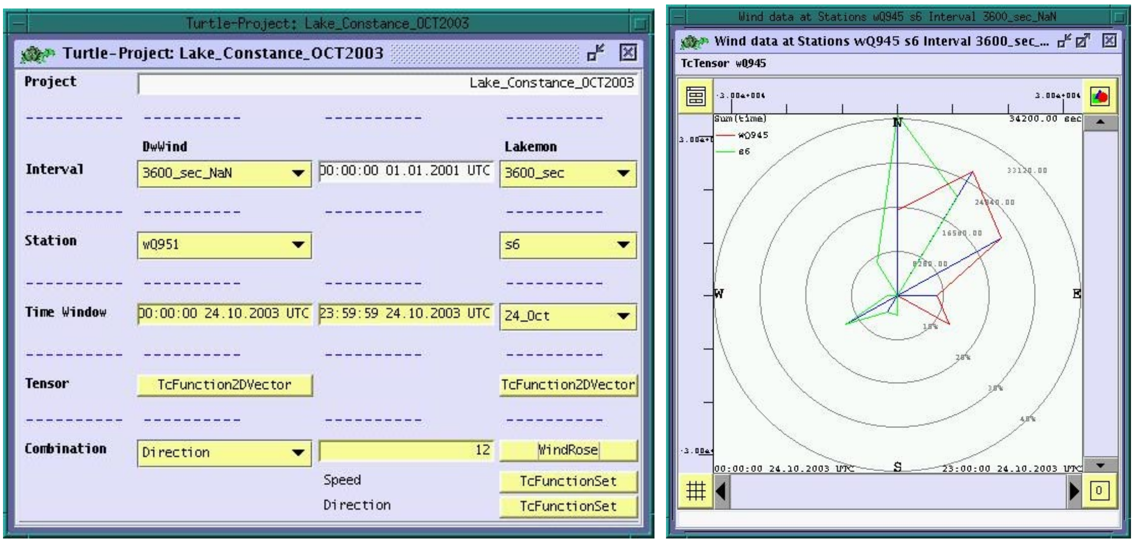

Figure 3: Wind Data Comparison

4.3.3 Reporting and Archiving

The performed measurement programme led to a huge amount of valuable data and corresponding information. A detailed reporting and complete archiving ensure the long-term access to the obtained information. Traditionally, this has been done by printed reports and ASCII data files in software-depending formats. 'Turtle' supports this important task by a new concept. The whole measurement data set was reported by generated HTML pages, including data tables, generated images for visualisation, and interactive features (JavaScript, Applets) for navigation and zooming in the measurement data space (station, time, time step size, and water depth). Additionally, all tensor objects were persistently stored in a self-describing XML format. We hope this way of platform- and tool-independent reporting and archiving will enable the reuse of the measurement programme results in the long run. However, published on CD/DVD or offered for downloading via the Internet the data can be used by partners from different disciplines with their different tools just now – an important step to support *inter*disciplinary and *inter*national collaboration in the *Inter*net.

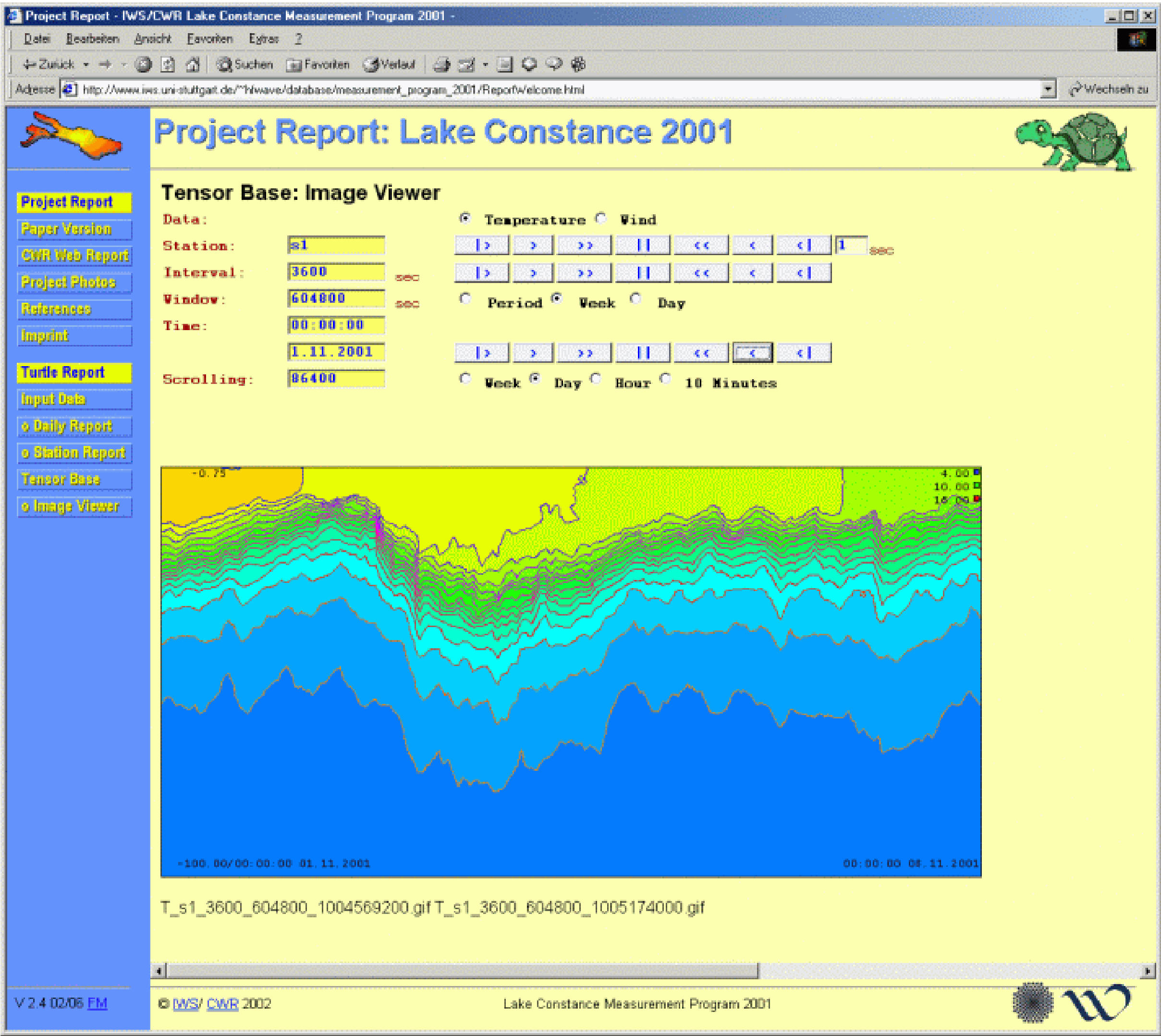

Figure 4: Report Example

5 Conclusion

Web-based information systems based on modern information modelling methods and platform-independent Web technology open a new level to support interdisciplinary and distributed collaboration in civil engineering. Measurement programmes and simulation experiments require such a support for flexible information handling during and after their performance. The applications of the Web-based information system ‘Turtle’ for the measurement programme ‘Lake Constance 2001 and 2003’ and other projects (resource management, flood management, morpho-dynamic simulations) confirm the potential of this approach. ‘Turtle’ offers an even more flexible tool to access and handle the measured data quickly with a tremendous effort (time) reduction for the involved experts. Of course, this approach can not produce explicit new physical insight – the data and the scientific analysis methods are still the same as in comparable measurement programmes and simulation experiments before. However, the application of this generalised approach provides amongst other important features:

- fast world-wide information access for on-line pre-analysis
- different interdisciplinary views on the same data set
- integration of different data sources on the same level as tensors
- support of distributed collaboration by information sharing instead of exchange
- flexible information ‘zooming’ on different time/space windows and scales

The generalised information modelling approach offers experts besides their conventional tools and methods a more generalised view on data and the opportunity to apply analysis methods from other disciplines. This is an important step for interdisciplinary collaboration. By reducing the effort/time for information handling and by increasing the flexibility for different information views such systems allow the involved experts to spend more time on their original task: the physical insight of the artificial infrastructure and its impact on the natural environment for engineering purpose.

6 Acknowledgements

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