

GIS PLATFORM FOR INTERDISCIPLINARY ENVIRONMENTAL RESEARCH

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ABSTRACT:

The environmental science domain provides new challenges for cartography. Obtaining accurate scientific conclusions, forecasting or validating models requires widespread temporal and spatial environmental monitoring as well as an appropriate visualization of the acquired information. A GIS Platform has been created in the frame of the COGEAR and Swiss Experiment projects that is able to integrate the available sensor information and to manage additional large topographic datasets needed for environmental research in one coherent platform. Such large datasets are for example the geological maps, the digital terrain model (DTM), satellite imagery or seismic events covering the entire Switzerland. The proposed paper presents the architecture and functionalities required for creating a flexible GIS platform for interdisciplinary environmental research.

Keywords: *Cartography, GIS platform, datasets, Environmental research.*

1. INTRODUCTION

Every country is exposed to a wide variety of natural hazards, often leading to substantial loss of life, damage to property or infrastructure. The number of natural hazards with devastating consequences is increasing especially in mountainous regions, as they are the most sensitive to human and climatic influences (*Hurni et al., 2006*). For example, the seismic risk in Switzerland may increase as a result of the more intensive settlement and economic harnessing of alpine regions. The assessment of the different hazards through advanced technology is promoted in order to serve as input for all measures of risk mitigation.

The research of natural hazards and the assessment of risks are currently demanding cartographic support that goes beyond classic topographic and thematic cartography. First of all, cartographic applications must be able to manage significant amounts of data. High resolution aerial imagery, digital terrain models, land use and geological information are just a few of the basic data required in a cartographic application that supports environmental research. Moreover, simulations of environmental processes often produces spatiotemporal, high-dimensional and large georeferenced data sets that must be integrated in a cartographic application in the same manner as basic topographic data.

Secondly, up-to-date and high quality data is necessary for the careful examination of hazards. As consequence cartographic visualizations must occur automatically and in real-time based on the most accurate data available. Environmental data captured by sensors is just one example of the data that must be visualized in real-time.

Finally, standards-based interoperability is a necessity when cartographic applications must cooperate with various other information systems that are in use in the environmental

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research domains. Standards enable the distribution of complex geographic information over the Web in a clearly implementable workflow.

These challenges can be illustrated with a GIS platform that is currently being created in the frame of the COGEAR (Coupled seismogenic GEohazards in Alpine Regions) and its umbrella project Swiss Experiment. The COGEAR project is an interdisciplinary natural hazard project for investigating the hazard chain induced by earthquakes. It addresses tectonic processes and the related variability of seismicity in space and time, earthquake forecasting and short-term precursors, and strong ground motion. The research focus lies on the physics of non-linear processes in relation to topography, geological disposition and slope stability. The tasks include the development and application of numerical modelling techniques, the assessment of the susceptibility to seismically induced effects and the installation of different monitoring systems. This project will prepare a follow-up risk-related study of impacts on buildings, infrastructure, and society (*COGEAR Project, 2010*).

The SwissExperiment project is an initiative of the Competence Centre Environment and Sustainability of the ETH Domain (CCES) which has been created to provide a platform for large scale sensor network deployment and information retrieval and exploitation. Its main goal is to enable effective real-time environmental monitoring through wireless sensor networks and a common, modern, generic cyber-infrastructure. New acquisition technologies will concentrate on allowing the deployment of high spatial and temporal resolution measurements performed by a large number of sensors with differing requirements for data rates, resolutions, embedded intelligence and cost. This infrastructure will be used to work efficiently and collaboratively in finding the key mechanisms in the triggering of natural hazards and efficiently distribute the information to increase public awareness (*SwissExperiment, 2010*).

Both COGEAR and SwissExperiment are Swiss country-wide projects. The scientific and organizational structure underlying these projects combines various disciplines to strengthen and extend partnerships for a well-directed multidisciplinary research. In COGEAR, under the leadership of the Swiss Seismological Service, the research is not only supported by experts in seismology, engineering geology, geodynamics, geotechnics, geophysics and soil mechanics, but also, through the Institute of Cartography at ETH Zurich, by cartographers.

2. THE ARCHITECTURE OF THE COGEAR GIS PLATFORM

2.1. User requirements

In the COGEAR and SwissExperiment projects, the main task of the Institute of Cartography is to integrate research data, sensor information and additional large topographic datasets needed for environmental research in one coherent platform. With a planned launch in January 2011, the COGEAR GIS Platform will allow to organize and access the available research data of the COGEAR and SwissExperiment projects in an intuitive manner, thus being a technological enabler of interdisciplinary environmental research and collaboration.

The first and foremost requirement is to visualize the available research data in order to geographically identify overlapping areas of interest. During the environmental research activities, researchers make field studies and simulations on specific test areas that are best suited for their investigations. These research activities generate datasets which may be of value to other ongoing investigations even if they have a different research focus. To enable

synergies, the main role of the GIS platform is to communicate ongoing investigations and their generated data to all potentially interested researchers.

The second requirement is to enable research data sharing among researchers. As different researchers use different data acquisition systems, different software packages and different formats for storing their data, it became imperative to find a solution for enabling data exchange coordinated through a common GIS platform. Moreover, it is required to offer fast access to official topographic and geologic data to all researchers, as geological maps, the digital terrain model (DTM) or satellite imagery are basic input datasets in all environmental research projects.

The third and most challenging requirement is to integrate and visualize sensor measurements. With the gradual availability of environmental monitoring systems offering real-time sensor information such as weather, soil and snow parameters, it is necessary to offer a visualization of these parameters in order to test and validate models on demand. Sensor data as well as the results of scientific analyses and fusion algorithms must be dynamically visualized in a form which is appropriate for interpretation in order to gain better insights and detect spatial patterns. This serves as an extreme illustration of the dynamic nature of the data that must be visualised in real-time and requires that visualizations must occur automatically from the available data sources.

2.2. GIS platform architecture

Due to the extreme heterogeneous and distributed nature of the research data, the solution was to design the platform's architecture upon the latest developments in GIS and Web Cartography. The COGEAR GIS Platform was designed to abide the generic, three-tier WebGIS architecture (Iosifescu, 2009) presented in Fig. 1.

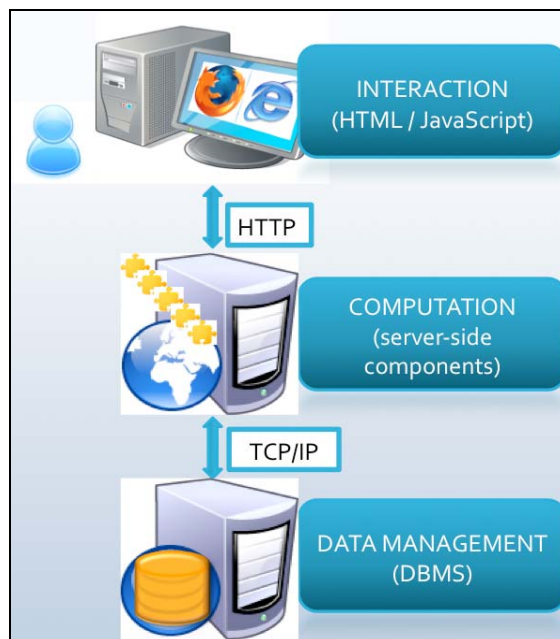


Fig. 1 Generic Three tier WebGIS architecture (Iosifescu, 2009)

The three tier WebGIS architectural design pattern has three components, namely a Data Management Component, a Computation and an Interaction component which correspond to the well-known data tier, logic tier and presentation tier (Eckerson, 1995). The data tier is represented by several distributed databases, the application tier is represented by services for visualization and download and the presentation tier is represented by the user interface. The fundamental characteristic of the three-tier architecture is its linear topology and the clear communication interfaces between components.

2.3. The data management tier

For spatial data management it is accepted that geo-spatial databases offer accurate procedures of data retrieval that can provide the basis for reliable interdisciplinary research (Gogu *et al.*, 2006). However, in a multidisciplinary environment, researchers perform data acquisition very differently, either with automatic acquisition systems such as sensors or with manual field studies followed by data processing in laboratories. Either way, they use different software packages and different formats for storing their data. These formats and procedures are best suited for their research intentions and it is not desired to modify their established individual workflows.

The solution to this dilemma was to add the database management system layer on top of their established workflow. The researchers can acquire data, create models, perform simulations and obtain results in their individual manner. They all agreed however to structure the input data and the final results in a database management system so they can profit from the advantages offered by a database regarding data structuring and retrieval. The project partners also agreed to use the free and opensource database PostgreSQL (PostgreSQL, 2010) due to its proven stability, its compatibility with opensource GIS software and its (absence of) licence costs. The free and open source nature was one of the major factors that influenced the decision, as commercial products usually have licence and/or training costs that prove to be prohibitive for small research projects.

Moreover, as the researchers are physically distributed in various places in Switzerland, the project decided for a common infrastructure distributed over the Internet. The main idea of this concept is the distributed management of the data in different databases. Each of these databases is located in the domain of a single data provider and is maintained by this provider. This simplifies the workflow of the data provider since the data is organized and stored according to the specific research needs of the individual partner. As an additional benefit, if one of the databases fails, the data sources of the other researchers are not affected.

The introduction of the databases to the individual research institutions was not effortless, but possible with the support provided by the Institute of Cartography in the incipient phases of the COGEAR project. The proven methodology consisted in training the research partners to develop and implement the databases in two separate steps. The first step implied the training necessary to specify a database schema for the existing data. The second step was to implement the schema in the database and to insert the data. Currently, several partners have made available research data (e.g. seismic stations, seismic events, boreholes, soil cracks, LiDAR data, and vibration recordings) and the number of shared datasets continues to grow gradually. In addition, several research institutions took the strategic decision to embed the database management systems in their research workflow as the definition of schemas for the data and research results showed several possibilities for improvement of the individual research workflow beyond the immediate goals of the

COGEAR project. As consequence, the schemas continue to evolve as new data sources are progressively added or as schemas are modified in order to support additional usage and query scenarios.

Beside the specific research data, the Institute of Cartography created a database for large topographic datasets in order to support the seismological research activities of the project. Such datasets are for example Geological Maps (scale 1:25000), the Digital Terrain Model (scale 1:25000), and satellite imagery (SPOT and LANDSAT) for the entire Switzerland. In addition, within the cooperation with the SwissExperiment project, the COGEAR topographic database is being enriched with the newest products of the Swiss National Mapping Agency, namely two height models of the surface and terrain (DOM and DTM-AV) and the high resolution airborne imagery Swissimage25. DOM and DTM-AV are high-precision modelling of the earth's surface below 2000 m based on high precision laser scanning from aeroplanes. Swissimage is a high resolution orthophoto mosaic taken with an airborne digital camera and having a ground pixel size of 25 cm.

The live sensor data is managed through Global Sensor Networks (GSN). GSN is a software middleware designed to facilitate the deployment and programming of sensor networks. It is a Java environment that runs on one or more computers composing the backbone of the acquisition network. A set of wrappers allow feeding live data into the system, while data streams are processed according to XML specification files. The system is built upon a concept of sensors (real sensors or virtual sensors) that are connected together in order to built the required processing path. Real sensors refer to live data streams while virtual sensors are used if the data is already stored automatically as files or in a database (GSN, 2010).

The basic GSN workflow illustrated in Fig. 2, consists of sensor nodes that would feed the data into GSN through a wrapper that decodes the serial data stream, then the real-time data stream can be sent to a database for recording and simultaneously made available over the Internet.

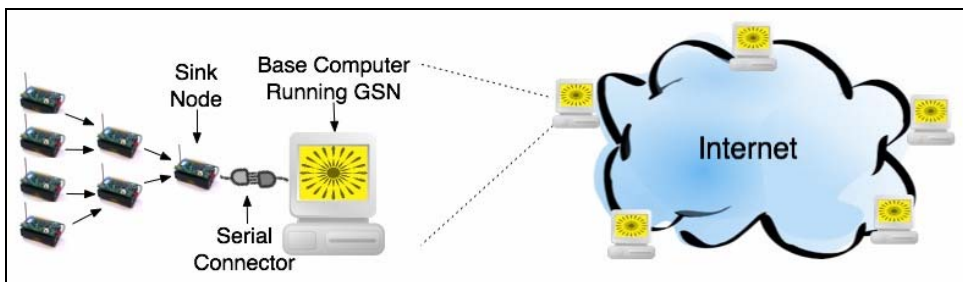


Fig. 2 Basic GSN workflow (GSN, 2010)

Currently various sensors are tested through GSN in preparation for larger sensor deployments. The current implementations of the Institute for Snow and Avalanche Research (SLF, 2010) are offering test sensor data streams such as air temperature, relative humidity, wind speed, wind direction, snow surface temperature, snow height, incoming shortwave and longwave radiation. With a planned support for PostgreSQL as database back-end, GSN not only provides the organisation and management of live sensor data, but will also have a seamless integration with the distributed database infrastructure of the COGEAR project.

The integration of distributed database infrastructure based on PostgreSQL and the sensor infrastructure managed with GSN, is a proof of concept that it is possible to manage research data, topographic data and sensor in one coherent geo-referenced manner.

2.4. The computation tier

The computation tier consists of services for visualization and download of georeferenced data. Based on the distributed data tier, a two step service provision workflow was designed and implemented. In a first step, Web Map Services (WMS) are offered on top of the distributed data sources. In a second step geoprocessing services are implemented to offer on demand download of datasets from a specific area. The download services allow the interactive selection of the area of interest, followed by data extraction (clipping) from the data source, and finally by the provision of a temporary download link to the extracted data.

From the cartographic point of view, we will focus on Web Map Services as the proposed platform for the visualization. WMS are standardized interfaces to provide maps with the GetMap request and metadata with the GetCapabilities and GetFeatureInfo requests (*ISO, 2005*). Topographic data is offered with a standard WMS implementation based on ArcGIS Server (*ArcGIS Server, 2010*).

Although not open source, the ArcGIS Server infrastructure is shared with additional projects such as the Geodata Visualization and Interactive Training Environment – GeoVITe (*GeoVITe, 2010*). The GeoVITe project aims to offer an easy-to-use online access to the most important geodatasets provided by the Swiss national mapping agency to ETH Zurich for teaching and research purposes. The common usage of the hardware and software infrastructure for GIS service not only creates synergies among different projects but also offers higher performance, stability and longer maintainability after the end of one individual project.

A special workflow was required for the integration of the sensor data and metadata. This workflow is based on the Geographic Markup Language (GML) for the exchange of sensor information and an extended WMS server, namely the QGIS mapserver (*QGIS mapserver, 2010*). QGIS mapserver is an open source Web Map Services 1.3 implementation but in addition it implements advanced cartographic features such as diagrams, patterns and custom symbols offered through an extended service interface (*Iosifescu et al., 2010*). As illustrated in **Fig. 3**, the extended service interface of the QGIS mapserver is used to transform the research data (in PostgreSQL) and the sensor data (in GSN) into a map that is ready to be displayed on demand over the Web.

GML (Geography Markup Language) is an XML-based geospatial standard developed by the Open Geospatial Consortium (OGC) which is widely accepted for spatial data exchange. GML contains a rich set of primitives such as feature or geometries, which are used to build application specific schemas or application languages in our case for sensor data. Since GSN allows the straightforward integration of new code, a GML output interface for point geometries was developed. This GML output interface is used by GSN to convert automatically the sensor data from the internal structure into GML when requested. QGIS mapserver complements the use of ESRI ArcGIS Server by enabling the on demand generation of maps from the real-time sensor data provided in GML format.

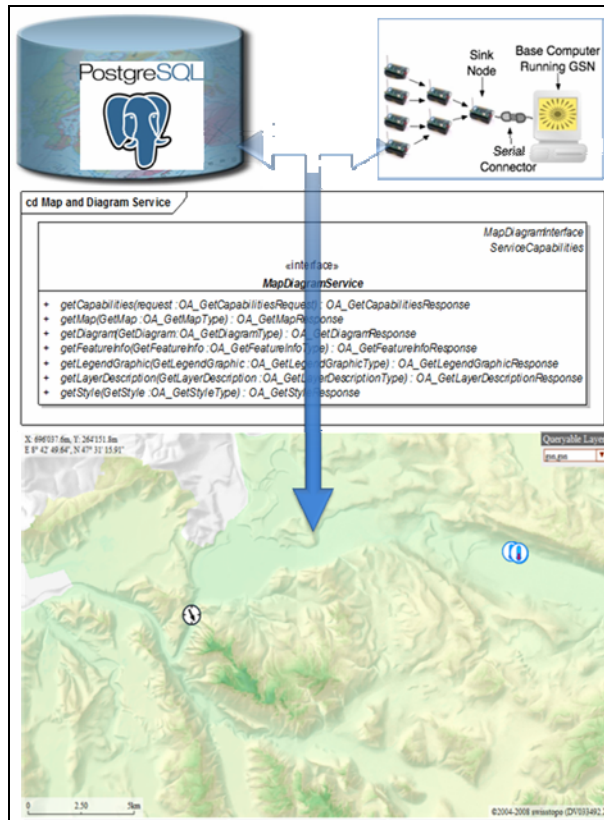


Fig. 3 Sensor data visualization workflow within COGEAR and SwissExperiment projects

2.5. The interaction tier

The service oriented approach applied in the Computation tier, allows any Graphical User Interface (GUI) to interact with the visualization and download services by using a simple request-response mechanism. The GUI sends a request to the web service and the server returns a response to the service consumer containing the expected content (map or data). Therefore it is possible to use any cartographic GUI framework designed for the web browser.

The GUI of the COGEAR development prototype shown in Fig. 4 is based on the advanced cartographic framework first described in (Neumann, 2005) which was further developed in the user interface of the GeoVITE project (GeoVITE, 2010). The framework is open source and available on the carto.net website (Carto.net, 2010). The COGEAR Interaction tier is therefore based on Scalable Vector Graphics (SVG) and it handles the map display, user interface and interactivity. The implementation of interactive functionalities is mainly based on ECMAScript/JavaScript, a client-side scripting language. The ECMAScript allows modifying the SVG Document Object Model and therefore implements the user interaction in the browsers that natively support SVG such as Mozilla Firefox, Opera or Chrome.

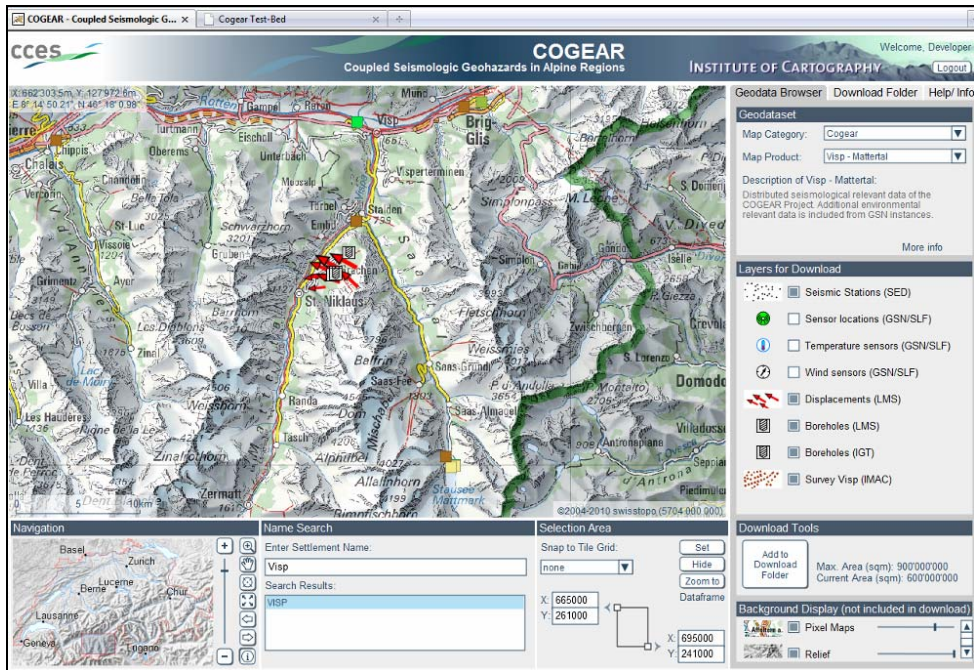


Fig. 4 COGEAR GIS Platform Development Prototype
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The user friendly layout of the SVG interface was chosen as a suitable front end for accessing the GIS platform's interactive functionalities. The simple design and placement of GUI elements enforces the intuitive recognition of the functionalities that are made available through the interface. These functionalities, which encompass spatial navigation, layer management, presentation of additional information and data download are to be presented in detail in the next section.

3. GIS PLATFORM INTERACTIVE FUNCTIONALITIES

3.1. Interactive functionalities

The *spatial navigation* controls are the elementary interactive components allowing zooming and panning the map as shown in **Fig. 5**. These controls are automatically supported by the SVG framework. The map navigation enable the user to choose his area of interest, to zoom in or out, pan, recenter, obtain full view or to go back and forth to previous views of the map. A zoom slider allows for continuous zooming. The reference map allows to reposition the map extent and to get local-global orientation cues. An additional search form assists the user to navigate by introducing a settlement name from the area of interest and then zooming to the found search results. Coordinate display on mouse move and an adaptive scale bar provide additional orientation and scale information.

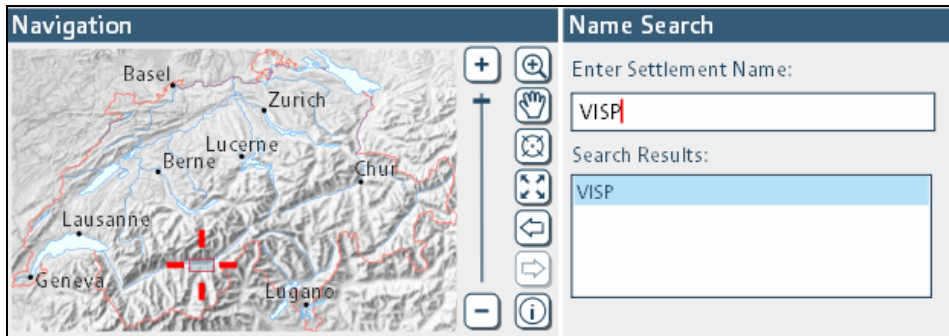


Fig. 5 Spatial Navigation Control of the COGEAR GIS Platform Development Prototype

The *layer manager* shows and hides map layers. It allows the user to select and deselect them with a checkbox from a list. It also contains a short description about the map category of the displayed layers and provides a legend for each layer as presented in Fig. 6.

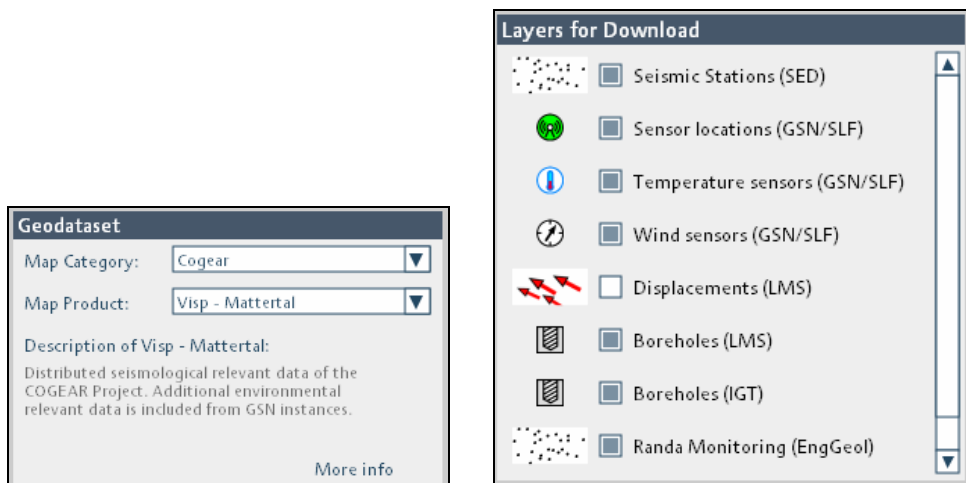


Fig. 6 Layer Management of the COGEAR GIS Platform Development Prototype

Selected *attributes and additional information* can be displayed for research datasets where such information is available. When using the Info tool, additional information can be triggered with a mouse click and can be displayed in a separate window or embedded in the view. This additional information is illustrated in Fig. 7 for a borehole and a sensor, but its layout and design is very flexible. Researchers can on one side prepare external Web pages that are appropriate to explain or offer additional cues for the datasets visualised in the map. Moreover, the GetFeatureInfo operation of the WMS can automatically generate a Web document for listing the important attributes of the feature of interest.

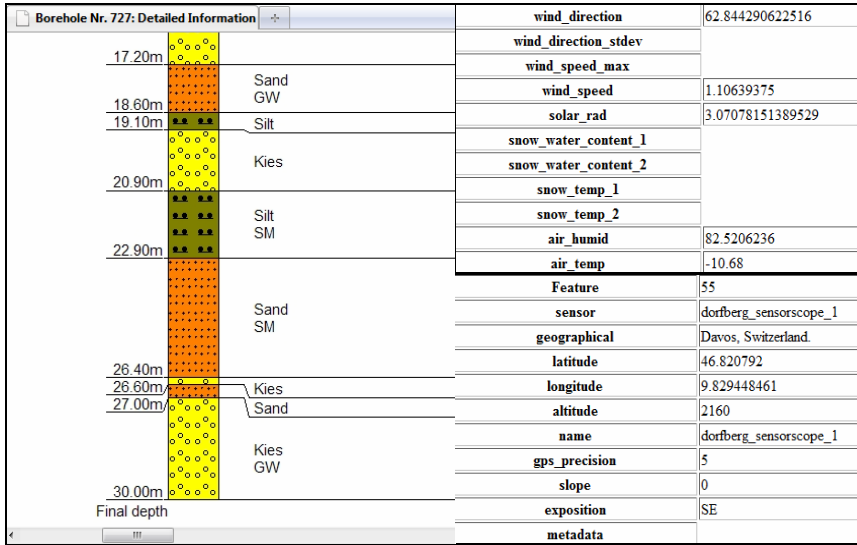


Fig. 7 Example of Additional Information Display of the COGEAR GIS Platform Development Prototype

The GIS platform offers the users the possibility to *download the visualized datasets* (when download is available for the corresponding datasets). The placement of the download controls was developed in cooperation with the GeoVITe project. The GUI design for download management shown in Fig. 8, allows the user an optimal access to the download controls for selecting/deselecting layers and for selecting the size of the area for download. Moreover, the download folder enables the user to manage the selected downloads individually.

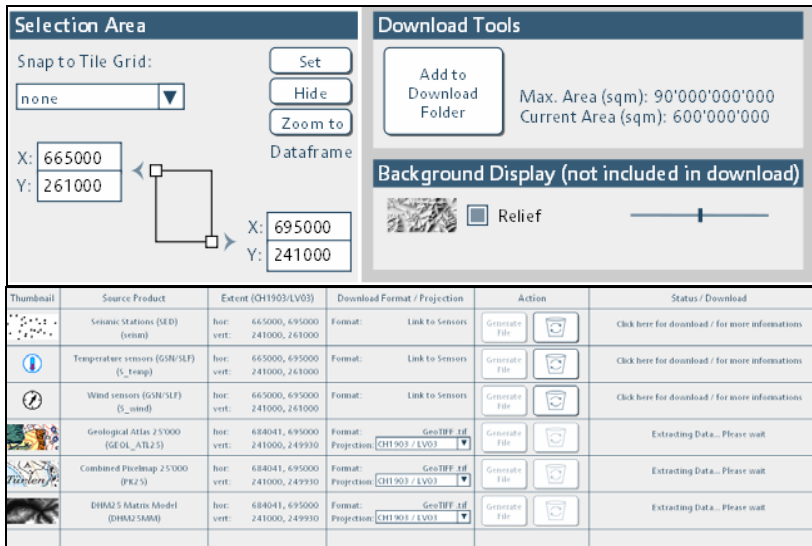


Fig. 8 The Download Controls of the COGEAR GIS Platform Development Prototype

3.2. Visualization of sensor data

Although in a prototype stage, the system already shows its potential for environmental monitoring and decision support. Sensor information such as temperature, wind speed, wind direction, solar radiance is represented on maps in real-time using enhanced cartographic descriptions. Such cartographic descriptions allow defining a desired map symbolization that is decoupled from the physical data. In this manner, visualizations are created in real-time from the latest data available. The monitoring of streamed data can provide an insight in many natural processes as for example, the local wind currents in a mountainous region. This can be observed from the representation of the wind direction on the map using arrows. Moreover, several layers and sensor measurements types can be overlaid in one map frame for an overview of the environmental parameters in the area.

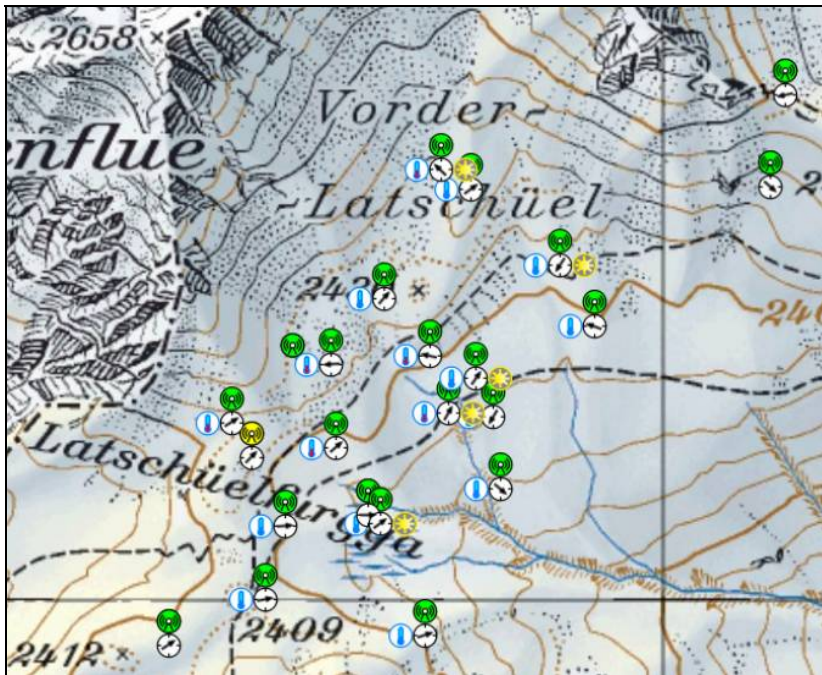


Fig. 9 Overlay of several types of sensor measurements in the COGEAR GIS Platform Development Prototype © SwissExperiment partners & swisstopo (5704 000 000)

As shown in **Fig. 9**, the system can be currently used for the monitoring of sensor status (green – the sensor is delivering data, yellow – the sensor has errors in the data provision) and for the monitoring of the streamed data (sensor measurements related with the color, shape, size and rotation of map symbols). The basic functionalities are already available and the system will be further refined and developed, mainly with cartographic tools for visual data mining. The cartographic tools will improve the possibilities to derive new information by offering visualisation of interpolated sensor measurements and by allowing users to define class boundaries and set thresholds interactively.

4. CONCLUSIONS

The environmental science domain aims for widespread temporal and spatial environmental monitoring as well as an appropriate visualization of the acquired information. A GIS platform can support the multidisciplinary research efforts by offering functionalities for intuitive and on-demand access to the necessary research data.

The intermediate results of the COGEAR and SwissExperiment projects prove the viability of a distributed access to organized data collections over the Web. The concept of distributed data access allows for flexible, evolving database schemas that are adapted to the specific research tasks of the individual partners. The use of services allows for low maintenance costs and straightforward integration with any given user interface. Finally, an intuitive cartographic presentation of the data has the potential to improve the insight in many environmental processes.

The COGEAR and SwissExperiment projects are supported by a functional GIS platform. Based on complementary use of commercial and open source software, the platform is able to provide a solid foundation for the future multidisciplinary research activities.

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