Development of an Internationally Applicable Geographic, Meteorological and Snow Cover Information System to Support Road Maintenance Operations

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ABSTRACT

A new Java-based information system to support wintry road maintenance operations is under construction. It was designed to combine modules related to geographic, meteorological and snow cover information. To facilitate international application, it was based on global topographic datasets such as products from the Shuttle Radar Topographic Mission (SRTM, horizontal resolution < 100m) and on a meteorological forecast model data interface compatible with NetCDF and GrADS-readable formats. The downscaling system VERA (Vienna Enhanced Resolution Analysis), based on high-resolution terrain information, will be applied to add detail to meteorological model forecasts and to improve the analysis, using the readings of road weather stations.

Keywords: Road weather information system, GIS, VERA, SNOWPACK, snow cover information

1. INTRODUCTION

Sophisticated information systems are one of the key tools for the successful work of traffic operation centers. Among the various components of such systems are meteorological data (measurements of road weather stations, output of energy balance models, etc.) and geographic information. The latter is normally restricted to "dead", unchangeable background maps which include the positions of key roads and motorways.

One of the rare exceptions of this convention is WeatherPro (formerly WELS), a PC-based road weather prediction scheme ([5], [6], [9]). This system, developed and managed by WELS Research Corporation and Alden Electronics, Inc., was specifically designed for winter highway maintenance operations. It was in use at a number of traffic operation centers in the USA and Europe till 2000, when business activities were suspended due to economic difficulties. The system was based upon concepts of "hybrid modeling" ([4], [12]): a centrally operated, company-run independent mesoscale forecast model (the "WELS model") was used to feed a Graphical User Interface (GUI, see Fig. 1) which was operated in the highway administration offices and included a primitive geographic information system (GIS).

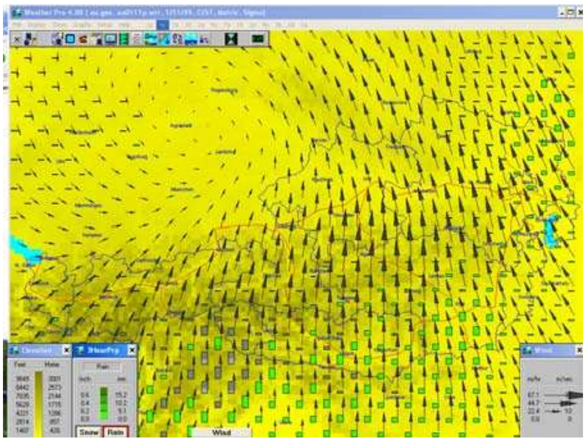


Fig. 1. Example of a Graphical User Interface employed by the WeatherPro system. A basic topographic map of the Eastern Alps can be seen where principal Austrian highways are drawn in red. Superimposed is a three hour forecast of the WELS-model, valid for 15 UTC, 11 January 1999. Winds are displayed in the form of arrows, while 3-hour precipitation amounts are depicted through color boxes (green colors for rain, grey colors for snow). Scales can be found in the lower left and right of the map.

2. RESEARCH MOTIVATION AND GOALS

Generally, the WeatherPro System was well accepted by the users and regarded to be an important help in the wintry road maintenance operations, especially during heavy snowfall events. However, further development of the GUI was substantially hampered by the fact that the source code of this interface was written in Prolog, a language originally not designed for graphical interface programing. Moreover, the use of a company-based weather forecast model has sometimes been subject to criticism. It was argued (although never proven) that the forecast quality of such models might substantially lag behind that of the computer-expensive models used by the big national weather services and international meteorological institutions.

Given the experiences above, it was decided to construct a new Java-based and technologically advanced geo-information system from the scratch, without using any source code, programming structure or the like from the outdated WeatherPro system.

The following principal research goals were defined:

1. *Easy international application.* Wherever possible, internationally recognized and common data formats shall be used. This counts for both the geographic and the meteorological part of the system. Easy transfer of the system to any geographic area shall be possible, and the inclusion of the results of different meteorological forecast models shall be straightforward.
2. *Use of a powerful GIS.* The currently available computer power allows the use of terrain resolutions much higher than those employed in the WeatherPro system, and various potential types of interaction between geographic and meteorological data provide unthought-of opportunities to improve the forecast of meteorological phenomena.
3. *Use of efficient downscaling algorithms for meteorological parameters.* The new system shall not be refined to a mere visualization of the output of meteorological forecast models. Especially over complex terrain, this output should be “scaled down” to resolutions far beyond that of the proper model, using sophisticated methods relying on topographic properties.
4. *Inclusion of snow cover modeling and visualization systems*. This can be achieved in collaboration with pertinent research institutes. Assumptions about the properties of the snow cover near highways are important to estimate the risk of drifting snow entering the roadway, whereas the stability of the snowpack on slopes above roads provides valuable hints about the hazard of lurking avalanches.

3. REVIEW OF THE DEVELOPMENT WORK

3.1 Principal remarks

System development was started within the framework of three different subsystems, related to geographic, meteorological and snow cover information. In the following sections a short review will be given about to which extent the subsystems have already been engineered and which working steps are still ahead.

In order to create the base for the international applicability of the system, from the start of the development process collaboration with meteorological organizations and snow research institutes from around the globe was established. This was partly to take advantage of the specific expertise of certain institutions, partly to tune the emerging system with different sorts of geographic and meteorological data. See Table 1 for further details.

The principal component of the system is a GUI, a user-interactive, graphics-based tool. As a programming language, the object-oriented and platform-independent Java is used. This provides the opportunity of executing the program in different operation system environments (Windows, LINUX, Solaris, etc.). Moreover, Java includes some specific tools and procedures related to the “internationalization” of programs. Using these techniques, a language switch was implemented at an experimental base, allowing the text of some important user dialog windows to appear alternatively in English, German or Spanish.

The source code is currently organized in two Java packages and around 100 classes, and its size is around 1.4 MB. It was compiled with the aid of the JBuilder software, accessing a number of external libraries like Swing and NetCDF.

Research Institution	Country/City	Contribution/Achievement
Alden/WELS (Alden Electronics, Inc./WELS Research Corp.)	**USA** (Boulder, Colorado)	Some basic ideas about the combination between geographic information systems and meteorological forecasts
WSL/SLF (Swiss Federal Inst. for Forest, Snow and Landscape Res., Swiss Federal Inst. for Snow and Avalanche Research)	**Switzerland** (Davos)	Java technology for GUI programming. Visualization of the output of snowpack models.
SENAMHI (Servicio Nacional de Meteorología e Hidrología)	**Peru** (Lima)	Start programming Java-based GIS. Tests of the prototype with a complete set of country-wide geographic vector data.
NIED/NISIS (National Research Institute for Earth Science and Disaster Prevention, Nagaoka Inst. for Snow and Ice Studies)	**Japan** (Nagaoka)	Continue GIS programming. Start programming interface for meteorological forecast models, using NHM model.
CRICYT/IANIGLA (Centro Regional de Invest. Científicas y Tecnológicas, Inst. Argentino de Nivelogía y Glaciología)	**Argentinia** (Mendoza)	Inclusion of high resolution terrain data (SRTM, Shuttle Radar Topographic Mission).
DGF (Departamento de Geofísica, Universidad de Chile)	**Chile** (Santiago de Chile)	Integrate visualization of the output of the MM5 model for two domains covering the Andes range.
IMG (Institute of Meteorology and Geophysics, University of Vienna)	**Austria** (Vienna)	(Ongoing): Display of observation data. Application of downscaling algorithms on meteorological analysis and forecast data.

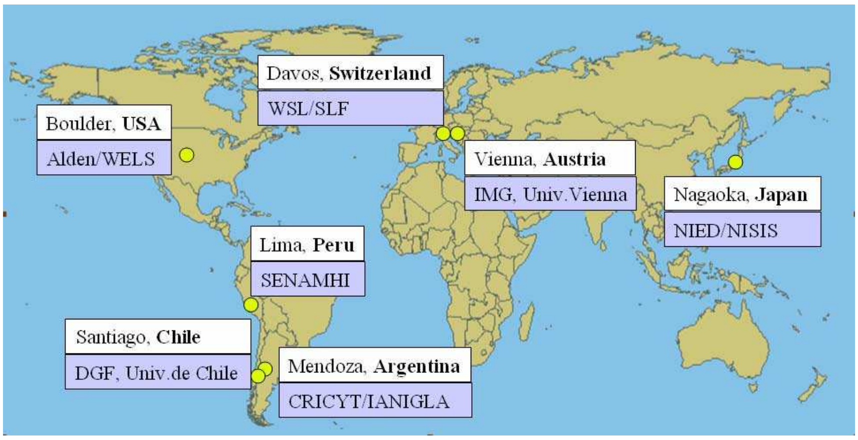


Table 1. Contributions of international research institutions to the development of the system. The world map to the left provides a review of the geographic locations of the institutes involved.

Data Name	Data Distributor	Horizontal Resolution	Coverage
Japanese Topographic Data	Geographic Survey Institute (GSI), Japan	1.5’ (~ 45m)	Japan
SRTM-Data (Shuttle Radar Topographic Mission)	US Geological Survey	3’ (~ 90m)	global
GTOPO30 (Global Topographic Data)	US Geological Survey	30” (~ 900m)	global

Table 2. Topographic data included in the system

3.2 The geographic information system

Work on the GIS is almost finished. This module was structured in the form of layers that can be selected for display independently of each other. This allows for the individual or combined visualization of city positions, vector data information (the road system, rivers, railways and boundaries) and of various terrain characteristics (elevation, slope and azimuth). The detail of geographic information used - five categories are available - is by default automatically adjusted when zooming or switching between differently sized predefined domains, using map generalization techniques. However, it can also be set by the user according to his specific needs. To give an example of default settings, for continental size display domains the state boundaries and capitals, principal highways and large rivers will be visualized, while for regional displays additionally province and district boundaries, minor roads, small cities, mayor villages and tributary rivers will pop up in the display.

For the construction of a system-specific terrain data base, the input data (see Table 2) were transformed to form five different resolution levels, each of these represented by a large number of “small” files in the binary ArcGIS GridFloat format to guarantee rapid data loading after the selection of geographic areas. The grid used for terrain visualization of the currently chosen geographic domain (holding the “screen geopixels”) is obtained by data interpolation from an adequate resolution level, considering both the screen resolution (a limiting factor) and the user’s resolution preference. A number of terrain manipulation facilities have been implemented, such as the suppression of selected height intervals to visualize road segments located above a predicted freezing level or within layers of low stratus clouds.

Data coverage is currently fragmentary and restricted to Japan, Europe and big parts of South America. However, the geographic database is constantly upgraded in agreement with external demand. Full data coverage, including exhaustive information about the road system, is currently just available for individual countries, such as Peru (Fig. 2). See Fig. 3 and Fig. 4 for screenshots of high resolution terrain representations for geomorphologically different regions.

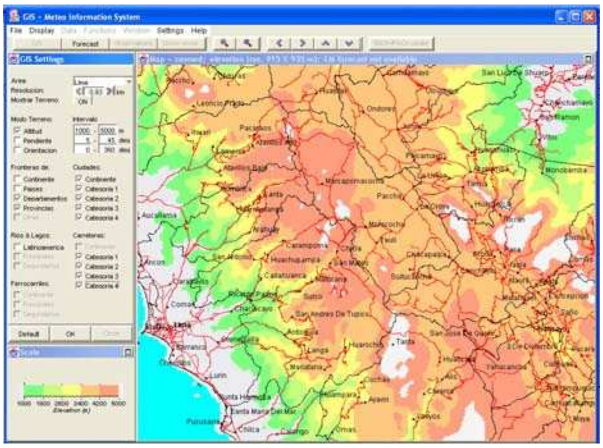


Fig. 2. GUI displaying geographic data for Central Peru between the capital Lima (lower left) and the Amazon basin (upper right). Topographic data of a resolution of approx. 900m are drawn in white for elevations above 5000m and below 1000m, an area of frequent coastal fog. Provincial and district boundaries are drawn in black, whereas the road network is depicted in red color.

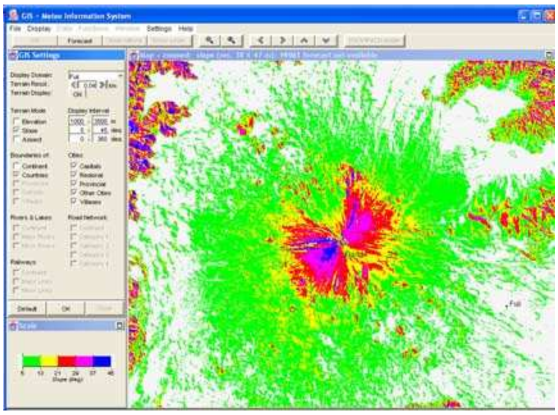
3.3 The meteorological information system

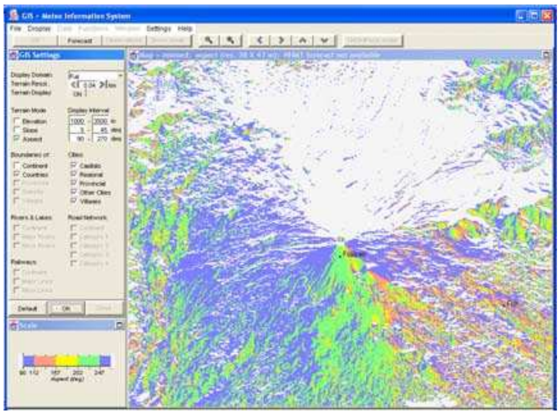
The meteorological subsystem is still under construction. With the terrain information as a background, currently the gridpoint output of two different numerical forecast models can be displayed:

1. *The NHM (Non-Hydrostatic Model).* This model was originally developed by the Japan Meteorological Agency. A research version of NHM, used during the development work, is run by the Nagaoka Institute of Snow and Ice Studies and operated with horizontal resolutions of 1-2 km over the heavy-snowfall areas of the island of Honshu.

2. *The MM5 model of NCAR/Penn State University.* The model version used is one operated by the Universidad de Chile in Santiago. It is at present executed on two domains (resolutions 15 and 45 km), covering the snow-prone Andean pass road between Santiago de Chile and Mendoza (Argentina).

Meteorological data formats currently readable by the system are NetCDF and simple GrADS-compatible binary formats; GRIB will follow in the near future. Thus the planned integration of additional models covering different areas (especially Europe) should be straightforward.





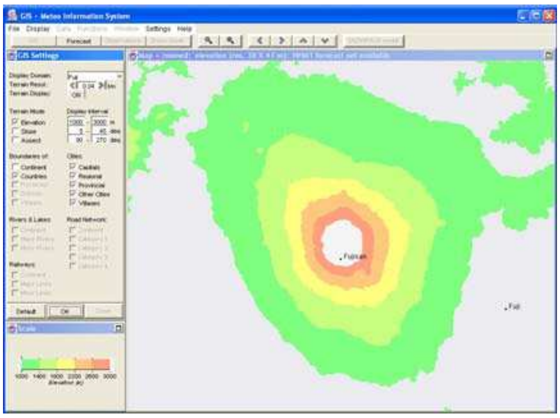
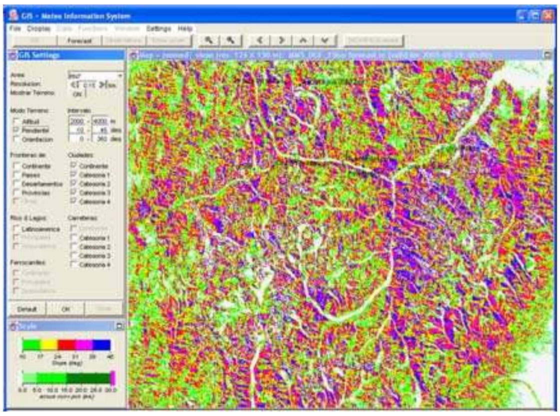
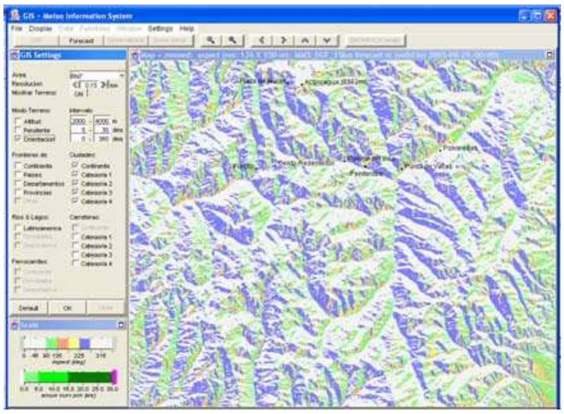


Fig. 3. Different modes of terrain representation (horizontal resolution: ~45m) for the Japanese volcano Fujiyama.
- Upper left: terrain slope (white colors are used for slopes < 5 degrees)
- Upper right: terrain aspect (north-facing slopes are drawn in white)
- Lower left: elevation (geographic pixels representing altitudes above 3000m or below 1000m are drawn in white)





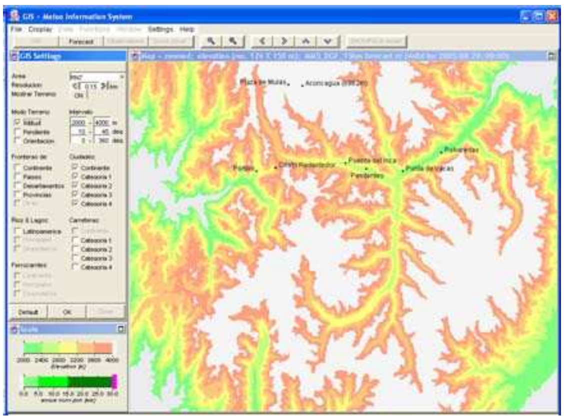


Fig. 4. Different modes of terrain representation (horizontal resolution: ~150m) for the Andes region between Santiago de Chile and Mendoza (Argentina).
- Upper left: terrain slope (white colors: slopes < 10 or > 45 degrees)
- Upper right: terrain aspect (north-facing slopes are drawn in white)
- Lower left: elevation (geographic pixels representing altitudes above 4000m or below 2000m are drawn in white)

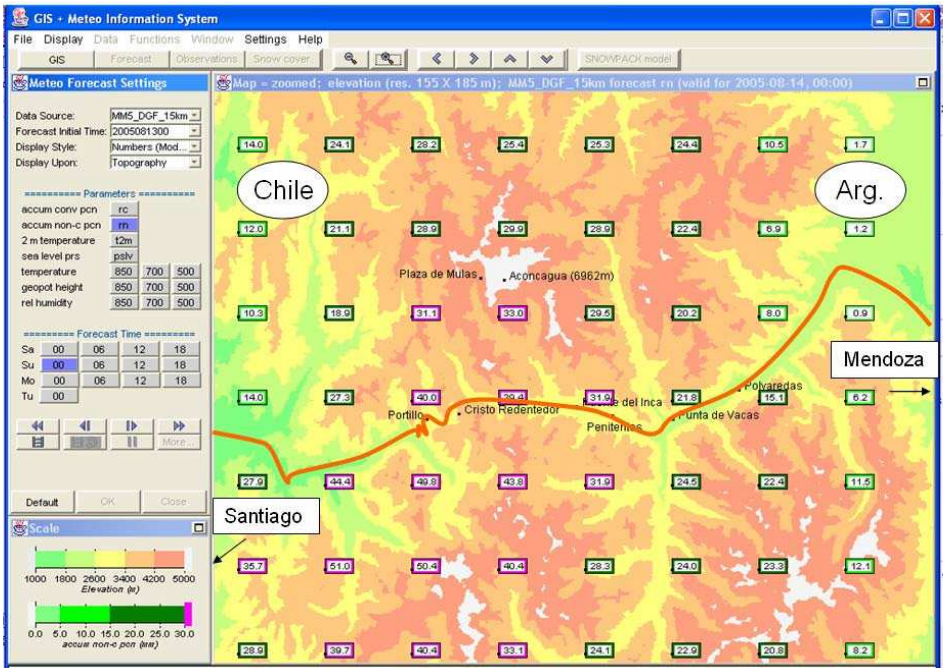


Fig. 5. On top of a map representing a section of the Southern Andes between Chile and Argentina, the forecast of the MM5 model for large-scale precipitation is depicted, related to a 24 hour-period starting 13 August 2005 00 UTC. During this episode heavy snowfalls accompanied by strong westerly winds caused the closure of the main highway (drawn in red colors) between Santiago de Chile and Mendoza (Argentina). The numerical values displayed at the model gridpoint locations are surrounded by frames colored according to the predicted precipitation amount. Check the color scales for precipitation and topography in the lower left of the graph.

The system already allows the display of a wide choice of direct model output and derived parameters, including those most relevant for traffic information centers (e.g. temperature, rain and snow accumulation, see Fig. 5). It can be chosen among a number of display styles like numbers and colored boxes. Forecast fields, related to the surface or to higher model levels, can be displayed for specific times or in a time-lapsing mode.

The high-resolution geographic information included in the system can be used to assess meteorological information for scales much smaller than those resolved by mesoscale models. The derivation of adequate techniques to process this “downscaling” is part of an ongoing research project, trying to integrate the VERA system (Vienna Enhanced Resolution Analysis, [10] and [11]) within the meteorological information module. VERA incorporates an objective, automated downscaling and analysis approach for meteorological data over complex topography. The method, working without first guess or prognostic model fields for initialization, is formulated for and applied to scalar and vector quantities on one- and two-dimensional domains. It includes a functional fitting approach based on a variational algorithm. Like for thin-plate splines, an integral of squares of second spatial derivatives is minimized.

VERA includes the influence of the high-resolution topography on specific meteorological parameters in the form of so-called “fingerprints” and will be applied both on analysis and on forecast data. By this it will also be possible to include for some parameters the area display of the deviation between observations and forecasts in the system. Application of VERA will also provide the opportunity to display details of meteorological conditions – present and future – along the extension of selected highways.

3.4 The snow cover information system

The physical snow cover model SNOWPACK ([1-3]), a Lagrangian finite element implementation, was primarily developed for the support of avalanche warning in Switzerland and is among the most advanced snow cover models worldwide in terms of microstructural detail. The model is mostly used for simulating the structure of the snowpack at the sites of high Alpine automatic stations, using their meteorological and snow measurements as an input.

In addition to stand-alone applications, SNOWPACK is increasingly utilized in a distributed way, simulating the snowpack for horizontal grids rather than just for individual point locations. SNOWPACK has been coupled with atmospheric flow and snow drift modules as well as with spatial energy balance models ([7]).

Both the output of the SNOWPACK model for individual sites and area representations of the snowpack can be included in the emerging information system, although the latter still requires some more research work in order the deliver reliable results. Concerning the graphical representation of the output of SNOWPACK for single-point locations, a graphical user interface called SN_GUI has already been constructed ([8]) and is ready for integration.

4. CONCLUSIONS AND FINAL REMARKS

The presented research effort embodies the first attempt to build up an internationally applicable system designed for the combined use of geographic, meteorological and snow cover information schemes. The work is already in an advanced stage. Some major modules still missing are the implementation of downscaling techniques for meteorological data and the area display of snow cover characteristics. In the past, the three types of information included in the system have been visualized rather independently of each other, using simple overlay techniques, but soon interactions between the modules and conditional display modes of the type "Show all gridpoints above 2000m, with a slope exceeding 30 degrees and a predicted fresh snow accumulation of more than 30 cm" will increasingly become important.

Finally it shall be noted that till now, it has primarily been focussed on setting the technological and theoretical framework for efficient development work. However, in the future the principal orientation of the work will be shifted to more practical aspects, keeping in mind the specific needs of traffic information centers for wintry road maintenance operations.

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