Proceedings of 8 ICSHMO, Foz do Iguaçu, Brazil, April 24-28, 2006, INPE, p. 2049-2057.

DEVELOPMENT OF A COMBINED GEOGRAPHIC AND METEOROLOGICAL INFORMATION SYSTEM FOR THE ANDES REGION

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RESUMEN

Dentro del marco de un proyecto de investigación internacional e interdisciplinario, con contribuciones y participación de institutos con investigación alpina y universidades de los Estados Unidos, Austria, Suiza y Japón, se construye un sistema combinando información geográfica y meteorológica para Sudamérica. El sistema, programado por Java, enfatiza particularmente a la región andina de Chile, Argentina y Perú. La sección geográfica incluye una topografía fundada sobre datos SRTM (Shuttle Radar Topographic Mission, resolución horizontal aprox. 90m) y representaciones de carreteras, vías férreas, ríos, fronteras y ciudades. Gráficas de la topografía del terreno (altitud, pendiente, orientación) son construidas instantáneamente para umbrales y resoluciones flexibles. Sirven como fondo para información meteorológica y nivológica (como cantidad de nieve fresca) que puede ser representada por una variedad de estilos. Será posible la visualización combinada de las observaciones de varias redes, de pronósticos numéricos de modelos como el MM5, y de errores de modelos. Para una variedad de parámetros meteorológicos, campos pronósticados y analizados podrán ser transformados a escalas de alta resolución, usando métodos de "downscaling" (VERA = Vienna Enhanced Resolution Analysis) desarollados por la Universidad de Viena.

Referente a rasgos del sistema relacionados especificamente a áreas montañosas, los datos SRTM permiten, en combinación con VERA, una buena estimación y visualización de áreas con acumulación de nieve y heladas. Existen planes para integrar el modelo suizo SNOWPACK en el futuro que hace simulaciones de las capas de la cubierta de nieve.

ABSTRACT

Within the framework of an interdisciplinary international research project with contributions from mountain research institutes and universities of the USA, Austria, Switzerland and Japan, a Java-based combined geographic and meteorological information system for South America is under development, with a special focus on the Andes region of Chile, Argentina and Peru. The geographic part of the system includes a topography based on data of the Shuttle Radar Topographic Mission (SRTM, horizontal resolution approx. 90m) and representations of roads, rivers, frontiers and cities (all stored in formats close to ArcGIS). On top of various modes of terrain (elevation, slope, aspect, all for freely chosen thresholds and resolutions), meteorological information can be visualized in a variety of styles. The combined display of observations from various networks, of forecasts from numerical models like MM5 and of forecast errors will be possible. For a variety of parameters, meteorological input data may be subject to downscaling procedures using the VERA system (Vienna Enhanced Resolution Analysis), developed at the University of Vienna.

Regarding features of the system specifically related to mountain areas, the high resolution terrain allows a good estimation of areas with snow accumulation in the case of forecast precipitation events. The easy detection and visualization of regions beyond the freezing level is possible. For the future the inclusion of the Swiss SNOWPACK model is planned.

1. INTRODUCTION

Sophisticated information systems with a specific focus on mountainous regions are one of the key tools for the successful work of traffic operation authorities, avalanche control centers and other state organizations and private enterprises whose revenue partly depends on the precise forecast of atmospheric conditions. Among the various components of such systems are meteorological observation and forecast data and geographic information. The latter is normally restricted to "dead", unchangeable topographic background maps which include the positions of political boundaries and some mayor cities.

One of the rare exceptions of this convention is WeatherPro (formerly WELS), a PC-based weather prediction scheme (Spreitzhofer 1997, 2000; Steinacker & Spreitzhofer, 1998). This system was in successful use at a number of weather-related enterprises and control centers in the USA and Europe till 2000, when business activities were suspended due to economic difficulties at the end of the "dot.com hysteria". The system was based upon concepts of "hybrid modeling" (Reiter 1991, Teixeira & Reiter 1995; Fig. 1): a centrally operated, company-run independent mesoscale forecast model (the "WELS model") was used to feed a Graphical User Interface (GUI, see Fig. 2) which was operated at the location of the weather-dependent institutions and included a primitive geographic information system (GIS).

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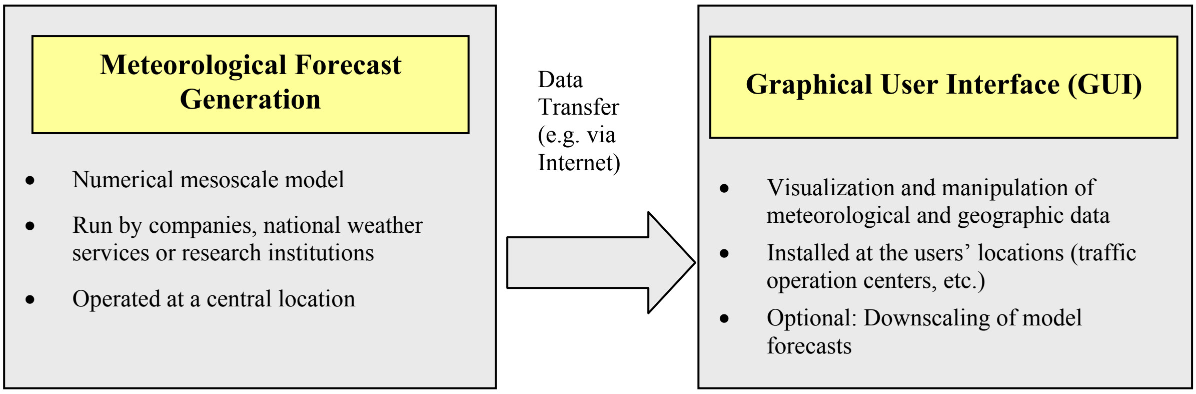


Fig. 1: Schematic review of the hybrid modelling approach

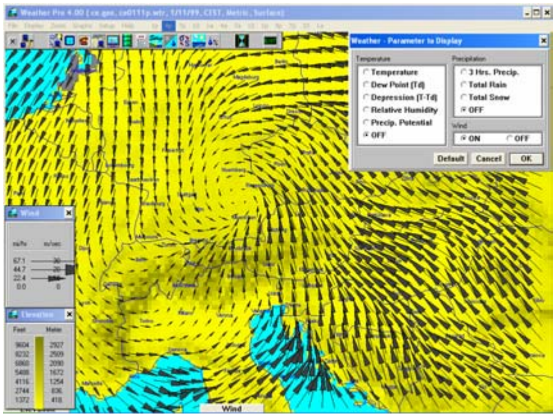


Fig. 2: Example of a Graphical User Interface (GUI) used by the WeatherPro system, displaying a wind forecast for Central Europe.

2. RESEARCH MOTIVATION AND GOALS

Generally, the WeatherPro System was well accepted by the user community. 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 the traffic network 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 (see Fig. 3). 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.

The system structure was set up according to Fig. 1. The principal component of the system is a GUI, a user-interactive, graphics-based tool, fed by a meteorological forecast model. The GUI software is operated at the user's location.

As a programming language for the GUI, 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 has been 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.

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. Concerning South America, tuning (with a focus on the Andes region) was done based on contributions from Peru, Chile and Argentina. See Table 1 for further details.

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 borders) 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 frontiers and capitals, principal highways and large rivers will be visualized, while for regional types of display additionally province and district boundaries, minor roads, small cities, mayor villages and tributary rivers will pop up.

For the construction of a system-specific terrain data base for South America, as an input two datasets provided by the US Geological Survey were used:

- SRTM-Data (Shuttle Radar Topographic Mission), horizontal resolution 30" (~90m)
- GTOPO30-Data (Global Topographic Data), horizontal resolution 3' (~900m)

These data 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 areas located above a predicted freezing level or within layers of low stratus clouds.

Concerning the system-specific terrain data base, resolutions of 900m are available for the whole of South America, while coverage with higher resolution data is currently restricted to parts of the Southern Andes. However, the geographic database is constantly upgraded in agreement with external demand. Full coverage with geographic vector data, including exhaustive information about the road and administrative boundary system, is currently just available for individual countries, such as Peru (Fig. 4). See Fig. 5 for examples of a high resolution terrain representation of the Andes region around the highest peak of America (Aconcagua, 6992m).

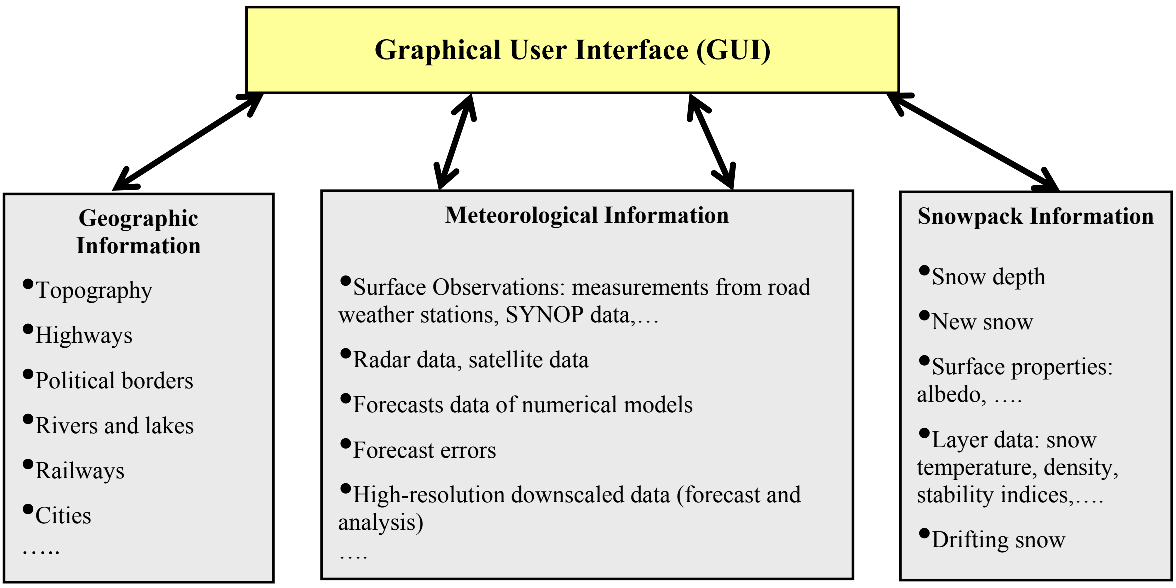


Fig. 3: Review of the types of information which shall be combined by the emerging system

Research Institution	Country/City	Contribution/Achievement
Alden/WELS (Alden Electronics, Inc./ WELS Research Corporation)	**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)	**Argentina** (Mendoza)	Inclusion of high resolution terrain data (SRTM, Shuttle Radar Topographic Mission).
DGF (Departamento de Geofísica, Universidad de Chile)	**Chile** (Santiago de Chile)	Include 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.

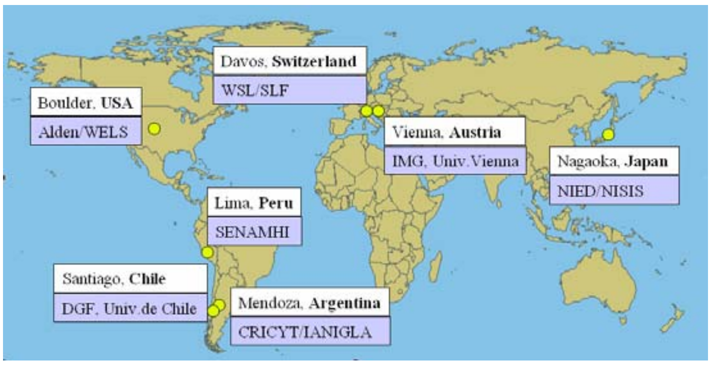


Table 1: Contributions of international research institutions to the development of the system. The world map to the left provides a review of the geographic locations of the institutes involved.

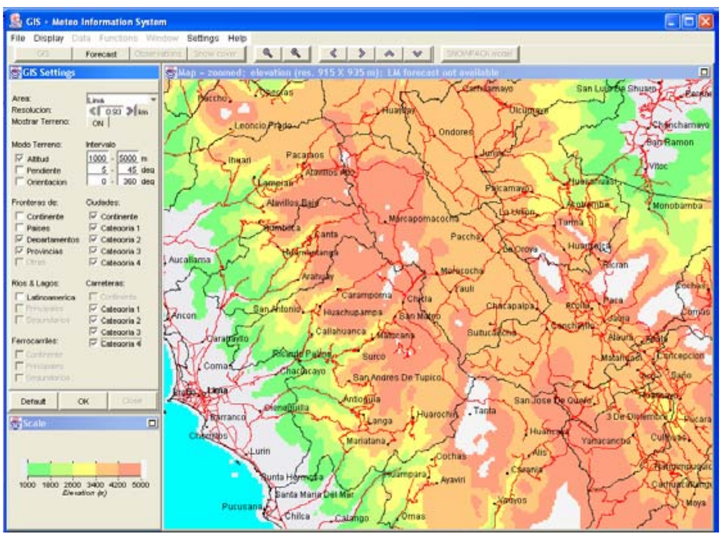


Fig. 4: GUI displaying geographic data for Central Peru between the capital Lima (lower left) and the Amazon basin (upper right). Topographic data of a resolution of approx. 900m are drawn in white for elevations above 5000m and below 1000m, an area of frequent coastal fog. Provincial and district boundaries are drawn in black, whereas the road network is depicted in red colors.

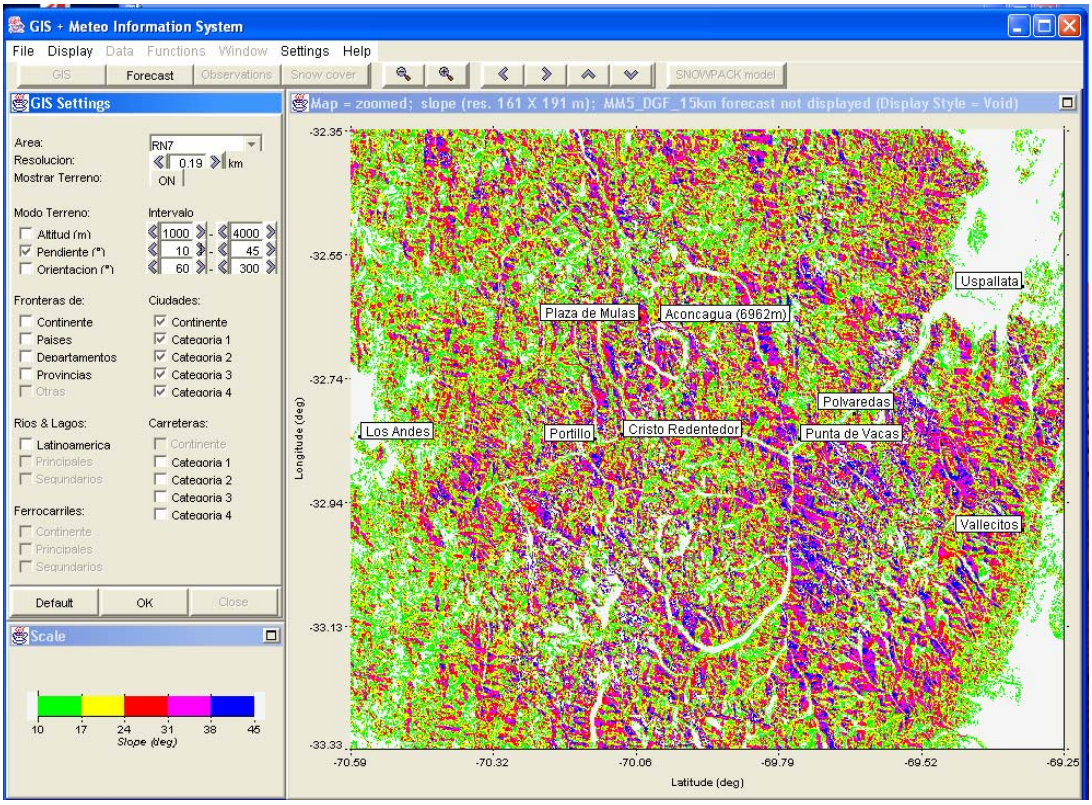


Fig. 5a.

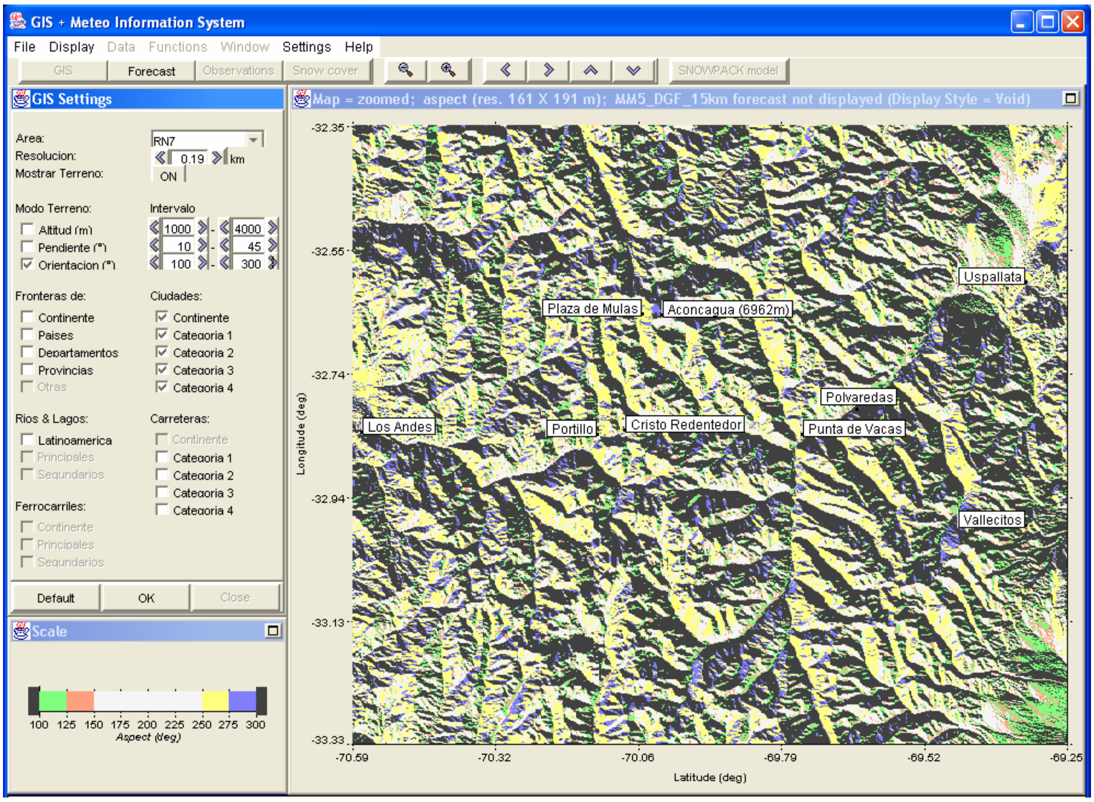


Fig. 5b

Fig. 5: Different modes of terrain representation (horizontal resolution: ~150m) for the Andes region between Santiago de Chile and Mendoza (Argentina). (a) Terrain slope (white colors: slopes < 10 or > 45 degrees). (b) Terrain aspect (north-facing slopes are drawn in black).

3.3 The Meteorological Information System

Construction and testing of the meteorological subsystem was started in Japan, using the output of the NHM model of the Japanese Meteorological Agency. For forecasts over the Southern Andes region, the MM5 model of NCAR/Penn State University is currently used. A version of this model, operated by the Universidad de Chile in Santiago, 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 (see Fig. 6). The gridpoint output of this model can be displayed with terrain information as a background.

Meteorological data formats currently readable by the system are NetCDF and simple GrADS-compatible binary formats; GRIB is supposed to follow in the near future.

The system already allows the display of a wide choice of direct model output parameters at model gridpoint locations, e.g. precipitation (see Fig. 7). The display of a number of derived parameters will be included shortly, including the interpolated and height-adjusted representation of surface temperature and fresh snow depth, which will yield to graphs such as those produced by the WeatherPro system for Europe (see Fig. 8). Predicted winds are displayed in the form of arrows. It can be chosen among a variety 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.

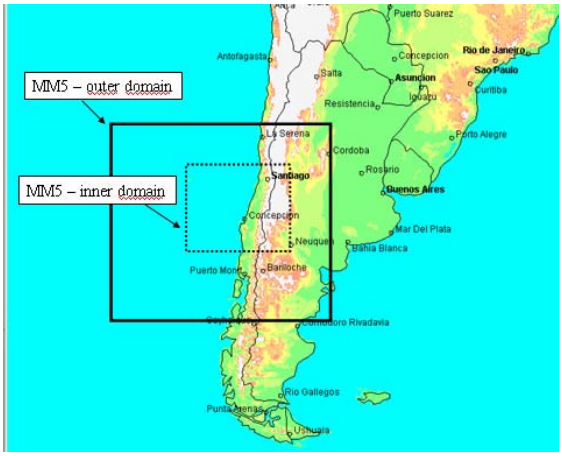


Fig. 6: Review of the two geographic domains covered by a version of the MM5-mesoscale forecast model, used at the Universidad de Chile (current: October 2005).

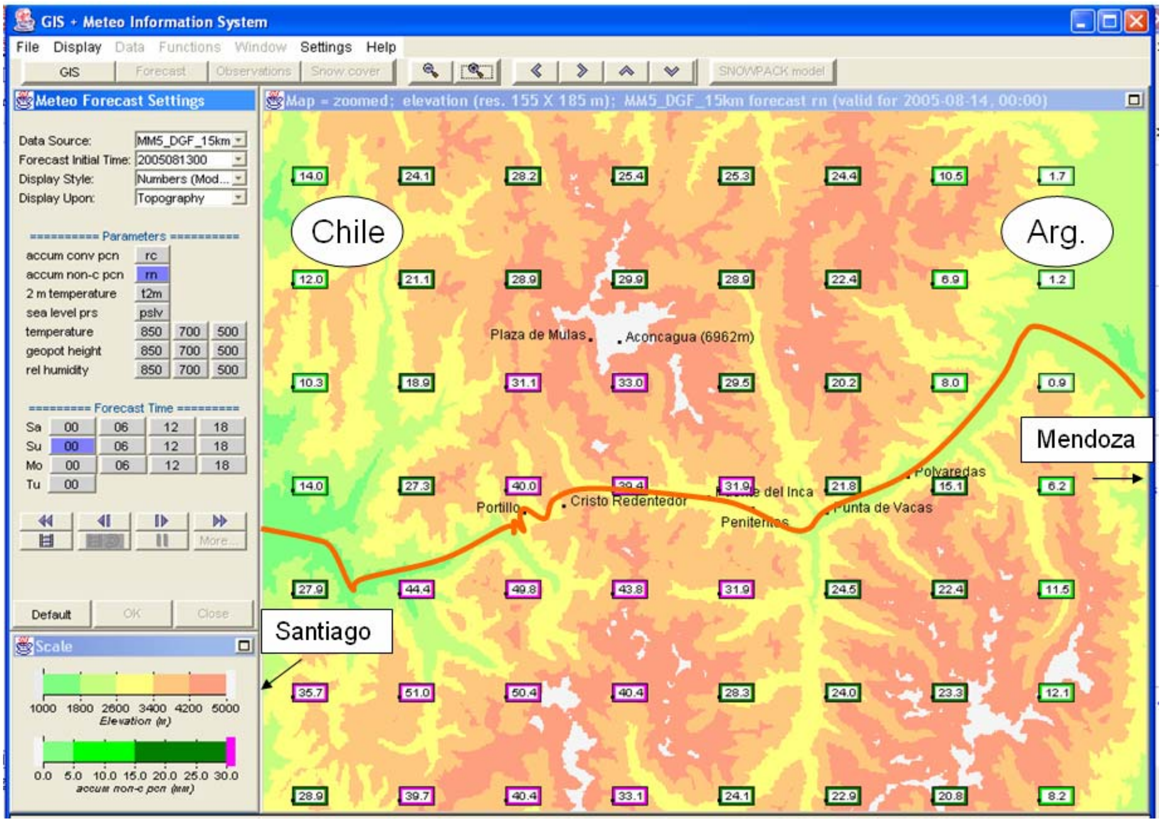
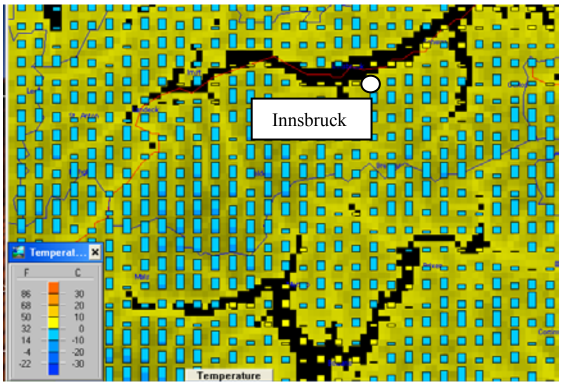


Fig. 7: On top of an elevation representation of a section of the Southern Andes between Chile and Argentina, the forecast of the MM5 model for large-scale precipitation is depicted, related to a 24 hour-period starting 13 August 2005 00 UTC. During this episode heavy snowfalls accompanied by strong 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.



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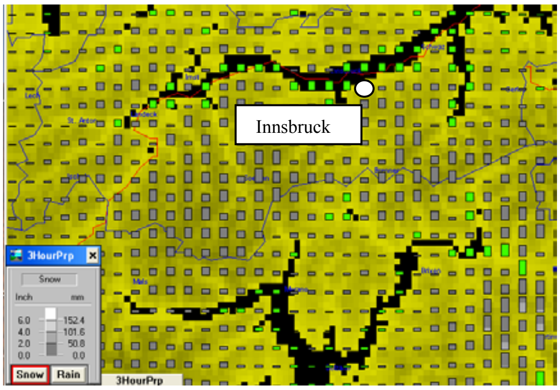

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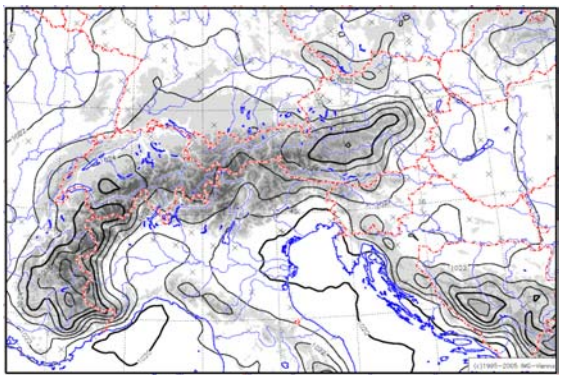
Fig. 8: WeatherPro-GUI, displaying the forecast for the area of Tyrol (Eastern Alps), valid for 11 January 1999, 18 UTC. Horizontal interpolation of the model gridpoint values and height-adjustment procedures allow the resolution of individual valleys; altitudes below 1000m are drawn in black color. (a) Surface temperature display. Blue colors indicate subzero temperatures, while yellow tones indicate values above the freezing level (check the scale in the lower left). (b) Display of three hourly precipitation. It is distinguished between rain (green colors) and snow (grey colors).



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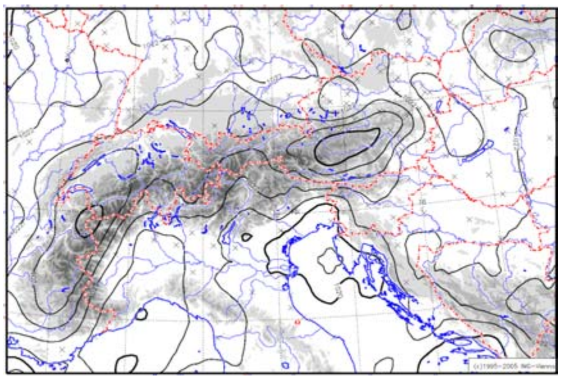

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Fig. 9: Analysis of the mean sea level pressure for Central Europe, valid for 31 March 2002, 03 UTC, based on a set of stations marked by crosses. The used contour interval is 1 hPa. The left-hand map (a), constructed using the VERA fingerprint technique, reveals many more details than the map to the right (b) which is based on conventional spline-based interpolation methods.

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, Steinacker et al., 2000 and 2006) 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" (see Fig. 9) and will be applied both on analysis and on forecast data. By this it will also be possible to include in the system for some parameters the area display of the deviation between observations and forecasts. Application of VERA will also provide the opportunity to display details of meteorological conditions – present and future – along the extension of selected highways.

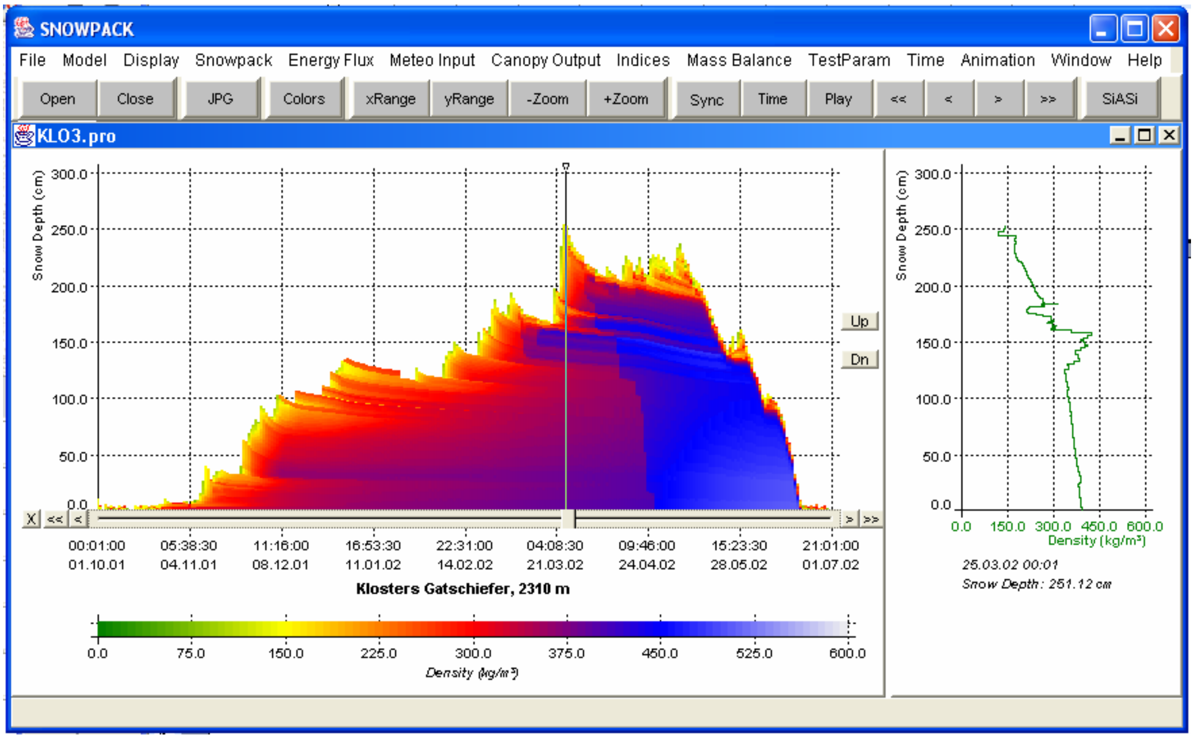

Fig. 10: Example of the main frame of the SN_GUI visualization. This is based upon a run of the SNOWPACK model for the Swiss site Klosters Gatschiefer, related to the 2001/02 winter season and focusing on snow density. The right-hand side displays a vertical profile of that parameter for the time marked in the temporal evolution profile given in the left side.

3.4 The Snow Cover Information System

The physical snow cover model SNOWPACK (Bartelt & Lehning, 2002; Lehning et al., 2002a,b), 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, and might also be employed over the Andes region.

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 (Spreitzhofer at al., 2002).

Both the output of the SNOWPACK model for individual sites and area representations of the snowpack could be integrated within the emerging information system, although the latter still requires some more research work and more powerful computers 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 (Spreitzhofer et al., 2004) and is ready for integration (see Fig. 10).

4. CONCLUSIONS AND OUTLOOK

The described research effort is already in an advanced, operationally applicable 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 (geographic, meteorological and snow-related) 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 will become increasingly important. Database queries such as “Show all areas above 2000m, with a terrain slope exceeding 30 degrees and a predicted 24-hour fresh snow accumulation of more than 50 cm” can deliver good estimates for the risk of avalanches.

The presented work embodies the first attempt to build up a technologically advanced system designed for the combined use of geographic and meteorological information schemes, with the additional opportunity to implement information about the snow cover at a later stage. The international and open format-design of the processed development work provides the opportunity to relatively inexpensively apply scientific achievements of well-known research centers to the Andes region.

ACKNOWLEDGEMENTS

Thanks go to all institutions and persons that delivered contributions to the successful advances in the research task presented, especially to Prof. E.R. Reiter and L. Teixeira, Ph.D. (key persons of WELS/Alden, USA), to WSL/SLF (Switzerland), SENAMHI (Peru), NIED/NISIS (Japan), CRICYT/IANIGLA (Argentina) and to DGF (Chile) (abbreviations are explained in Table 1).

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