Severe Weather Explorer – Interactive Visual Analysis of Large and Heterogeneous Meteorological Data

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Summary

In this paper we present the results of a joint research project between visualization researchers and experts on meteorology for the purpose of fast and interactive visual analysis of severe weather conditions. The starting situation was, that for severe weather forecasting data from multiple sources each are visualized separately. 3D characteristics of atmospheric data are displayed usually in a reduced 2D form. A general overview and understanding of the complete situation is thereby often difficult and very time-consuming, in some cases even impossible. Expert meteorologists are challenged by this situation especially in time-critical situations, e.g. short-term forecasts of hail or similar phenomena.

The goal of the "Severe Weather Explorer" project is the development of a new software technology for 3D interactive visual analysis of meteorological fields resulting from various data sources. The software tool combines three-dimensional visualizations of 3D radar data and results from short-term forecast simulation in a geo-referenced model with interactive visualization of multi-variate measured meteorological data from many data sources. The system also allows the definition of algorithms for the detection of severe weather conditions based on all input data. These algorithms can be automatically checked in realtime for each new measurement and/or simulation result and thus dangerous situations are emphasized for the expert meteorologist, who is responsible for severe weather warnings in shortest possible time.

The Severe Weather Explorer enables faster and more accurate warnings. Additionally meteorologists gain new insights in the complex correlations of the different data fields and thereby can improve warnings in a feedback loop.

1. Introduction

Severe weather conditions, as for example storm, hail, massive rain or snowfall, or similar events have an ever growing impact on the life of everyone as well as on the economy of our general society. With new technological resources forecasts and short-term analysis of these meteorological situations and possible implications become available and therefore are used more often.

Up to now the regular process for weather prediction has built upon data from many different sources, which are analyzed separately and the different results are then merged mentally by the meteorologists based on their expert knowledge. The main problems that arise with this traditional way of visualizing and analyzing the heterogeneous meteorological data include that data from different sources is visualized in different styles, 3D data is only displayed in 2D mappings, as well as interactive means to probe or query the data are usually not available. These problems challenge the meteorologists in gaining the full picture of the weather situation. This becomes a potential problem especially in time-critical processes as severe weather warnings, where often very fast responses and decisions are necessary.

Experts from the fields of interactive visual analysis technologies (VRVis) and meteorologists (meteomedia) have joined forces in the *Severe Weather Explorer* project [1] to come up with a new and much more powerful workflow to support the meteorologists in time-critical situations.

2. Related Work

There have been a couple of previous works in the field of interactive visualization of meteorological data. Hibbard et al. [2] have developed a software tool called Vis5D, which is one of the most known systems in this field. The system is capable of visualizing weather model data with 2D as well as also with 3D visualization methods, such as, e.g., iso-surfaces, direct volume rendering, cut-planes, or streamlines. The development of Vis5D has been stopped, but a couple of other software tools use it as basis for further development. The official successor is Vis5D+ [3], which is maintained amongst others by the visualization group at the National Center for Atmospheric Research (NCAR), US. This group also develops a suite of related visualization tools called “NCAR Graphics” [4]. A further noticeable software project building on Vis5D is the D3D project [5].

Besides the Vis5D based approaches, also a couple of other works exist, which have been targeted towards the visualization of meteorological data. One of these tools is the RASSIN software developed by Lux and Frühauf [6] at Fraunhofer together with the German Weather Service (Deutscher Wetter Dienst, DWD). This tool allows interactive visualization of simulation results. Jiang et al. [7] worked on handling and visualizing 3D radar data in a global context. Additionally, also selected automatic analysis steps are provided for the data to identify and depict mesocyclones. Gerstner et al. [8] also worked on visualization of 3D radar data. However, in contrast to our approach they applied semi-transparent iso-surface rendering instead of direct volume rendering (DVR). Riley et al. [9] worked on the other hand on techniques for visualizing weather phenomena as realistic as possible instead of providing interactive analysis tools.

Most of these systems and approaches are capable of supporting the meteorologists in visualizing and analyzing results of weather simulations or measured weather data. However, an interactive fusion of these (and many other) different data sources is mostly not well supported. Furthermore, the exploration of meteorological data is usually limited to a few not very flexible visualization techniques, as for example iso-surfacing of one data attribute or volume rendering for presentation rather than interactive analysis purposes. The analysis of complex relations between data coming from multiple sources is thereby supported in a non-sufficient way.

On the contrary, our developed methods and approaches allow a very flexible exploration and analysis based on an interactive visual analysis technique, which has been researched and presented previously in the scope of computational fluid dynamics simulation applications. The basic technology has been researched and implemented in a prototype software system called SimVis [10][11]. This new technology has successfully been applied in a couple of cases for different automotive applications (a) several simulations of different injection layouts for a high-performance 2-stroke engine have been interactively analyzed and compared using the SimVis technology [12]; (b) the detailed analysis of the periodic regeneration phase of a diesel exhaust system consisting of a catalytic converter and a diesel particulate filter [13]; (c) a large and complex data set resulting from CFD simulation of fluid flow in a cooling jacket for car engines has been interactively explored and analyzed leading to suggestions for geometry improvements [14]. Besides these automotive applications, the SimVis technology has already been successfully applied in two special meteorological cases before this project [15][16]. Both have dealt with the interactive visual analysis of very large data sets resulting from hurricane forecast simulation by the NCAR and have proven the benefits for interactive analysis of complex relations in meteorological data.

In another very recent work, Kehrer et al. [17] have applied the SimVis approach to climate simulation data sets for supporting the climate research experts in the process of generating hypotheses, which are further investigated afterwards for detecting trends in climate changes.

3. The Severe Weather Explorer

The Severe Weather Explorer is built on the SimVis technology as described above. The basic technological aspects of SimVis are the following:

- **Multiple linked views:** different aspects of the data are shown not only in one view, but usually in several views. The views in the SimVis approach are linked, which means, that interaction in one of these views can be transferred to modify some or all of the other views immediately. The views in our multiple views setup can be all of different type, but don’t have to be different. An example of a typical SimVis setup as employed in the Severe Weather Explorer system is shown in Figure 1. A *Selection View* (lower left) is used to interactively specify the spatial region of interest in the data based on available data in the source directory. A Scatterplot View showing the distribution of 2 different attributes of the simulation data is shown on the lower right. Two 3D views are available for interactive visualization of the temporal and spatial dimensions of the different data sources (radar, model, and station data). In principal an arbitrary arrangement of views is available in the SimVis framework.
- **Interactive Brushing:** One method to graphically select data on the computer screen is called brushing, where the user graphically marks data items shown on the screen. In the SimVis framework, brushing is available in all attribute views (Scatterplot and Histogram Views). In the scatterplot in Figure 1, lower right, for example all data items exhibiting a low value of likeliness of clouds (x-axis) have been brushed (red data points).
- **Focus+Context Visualization:** Focus+Context visualization is a concept employed to gain overview in very large data sets. When visualizing large data sets, the question of what to show, and what not is often more important than how to show every single data item, as this might not be possible on the limited screen space. Discriminating the data into parts which are in focus, and the rest (the context) is a mechanism to gain overview over the important structures for the analysis. In SimVis, all views employ this focus+context visualization, either through assigning different

colors (eg., red points for selected data items in the scatterplot) or through transparency in volume rendering (see cloud structures in upper left 3D view).

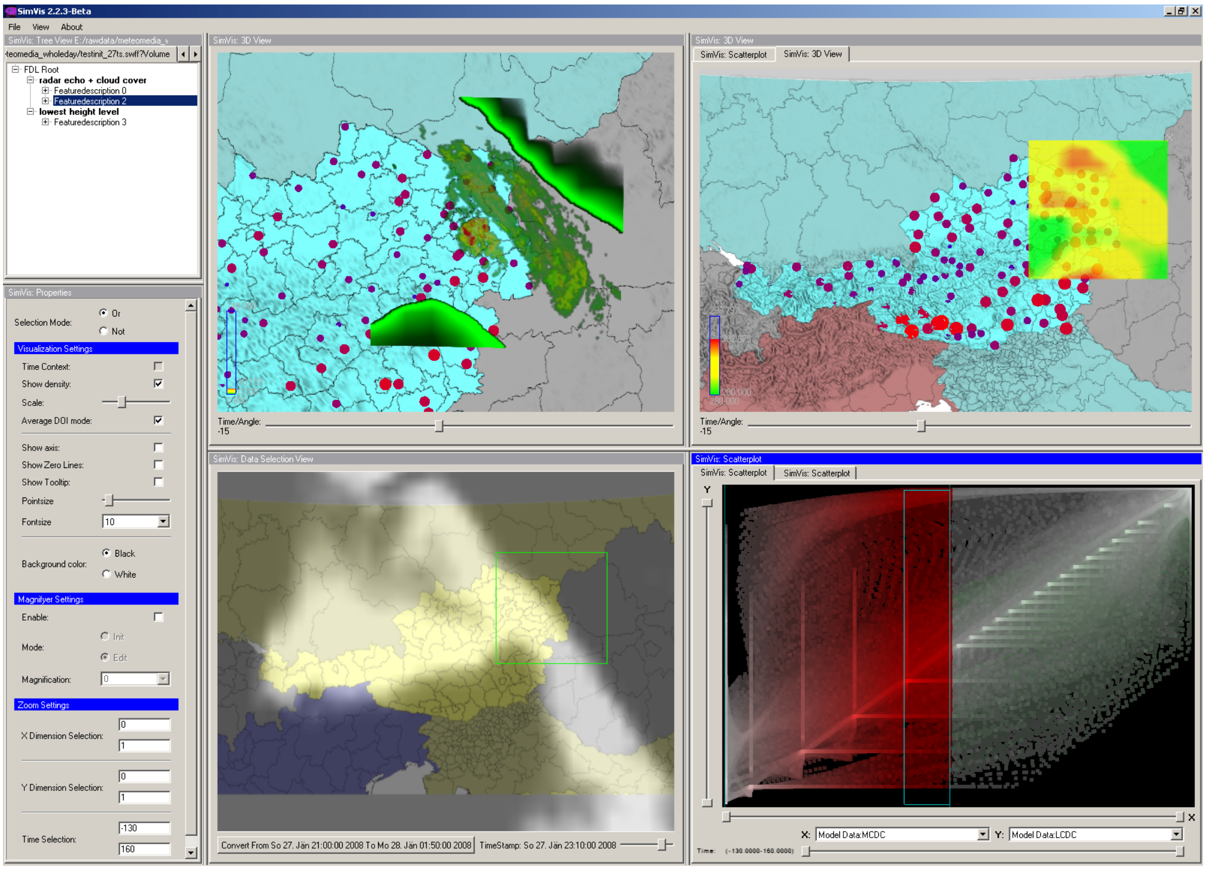

Figure 1: A sample Severe Weather Explorer scenario: 4 views are used to select and display different aspects of the data. The *Selection View* (lower left) is used to preview the data available in the specified data source directory. A *Scatterplot View* (lower right) is used to interactively specify interesting regions in the data based on selected attributes. Two *3D Views* (upper left and right) are used to view different aspects of the multi-source data in a 3D focus+context style. Control over view settings and parameters of the currently active view are provided on the left of the screen. (Details are in the text)

Based on these concepts of the SimVis technology, we have extended the prototype framework in several aspects to build a suitable system for exploration and analysis of severe weather conditions. The first extension deals with the handling of data sources. We enable to fuse data from different sources in one analysis session. The current data sources used are 3D weather radar, measurement information from weather stations, model output data of forecast simulations as well as the geometrical information of the Austrian landscape. Special challenges in fusing these data sources arise from both, different spatial extensions and attribute values as well as also from different temporal resolutions of the data. 3D radar data, for example, is updated every 5 minutes, and is streamed to a directory, where it is available for immediate analysis with our system, whereas station data is only available on an hourly basis. The simulation results on the other hand are also available for every hour, but the temporal domain spans the future instead of the past as is the case with all the measured data. Of course, simulated data can be also stored and is available later on for evaluation against the real world behavior.

Regarding the visualization and analysis methods, new techniques have been realized in the scope of the project, too. Besides the *Selection View*, which is especially designed for handling the weather data, also new visualization methods for station data (see 2D spots in the 3D views of Figure 1), as well as fused volume rendering of simulation and measurement data (see Figure 1, upper left view) and the display of textured geometry models of the landscape for orientation have been developed. Furthermore an interface for deriving new attributes out of the existing attributes in the data has been realized, which allows arbitrary formula definition. These derived data rules can be stored and reloaded, which helps the meteorologists to quickly assess the potential danger in daily routine data analysis. The system is also capable of semi-automatically reloading actual weather information whenever it becomes available and adopts the visualizations based on the same selection and specification algorithms applied beforehand. This helps to speed up the process of analysis in critical situations, where quick decisions are necessary to warn the respective sites about the approaching danger.

4. Application Results

Two examples showing the application of the Severe Weather Explorer system in two different severe weather condition cases over Austria are given in Fig. 2 and 3.

Figure 2 shows the analysis of a super cell over Tirol/Austria. On the left side a view from south (Italy) in the direction of north (Germany) is shown, the super cell and its vertical dimensions become clearly visible from the 3D radar data over Tirol (cyan in the middle). The skewness of the cloud regions with highest intensities becomes easily visible, indicating a dangerous threat of strong hail events in the direction of further movement of the cell. On the right a view from above is provided, enabling a better localization of the 3D focus of the radar data.

Figure 3 gives another example for the interactive exploration and analysis of severe weather conditions. A squall line, which has crossed (mainly) Lower Austria and Vienna on June 22nd, 2007 has been analyzed. Again, 3D radar intensities are volume rendered. Two different foci have been defined. On the left only clouds exhibiting the highest intensities in the radar data are shown. On the right a more complete image of the whole cloud structure is presented.

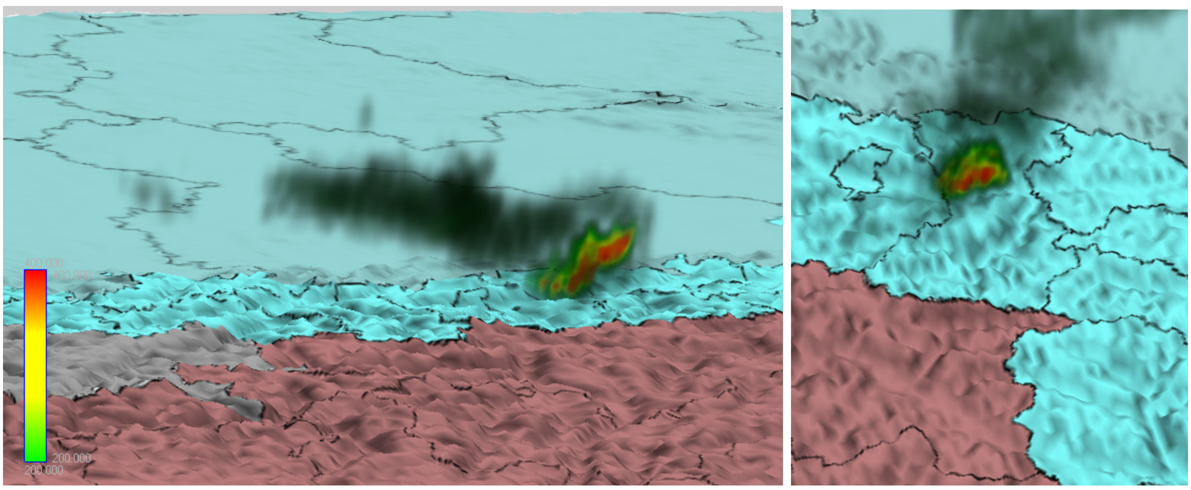

Figure 2: Application of the Severe Weather Explorer for the detection and analysis of a super cell on August 2nd, 2007 in Tirol/Austria. Left: looking from the south. Right: A view from above. (Details see in the text).

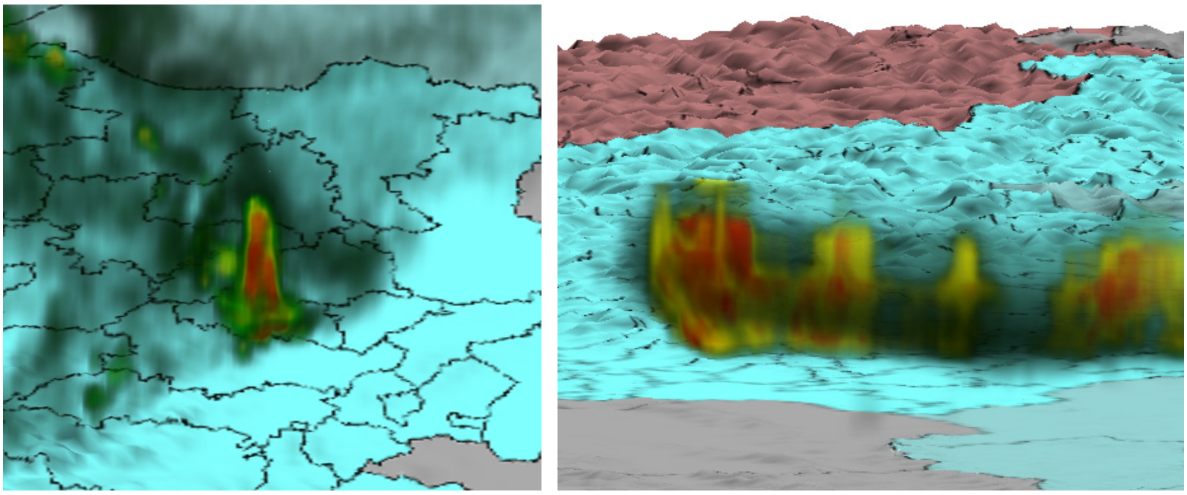

Figure 3: Analysis and exploration of a severe squall line over the Lower Austria and Vienna region on June 22nd, 2007. Left: The most severe intensities reached vertical dimensions of clearly over 10km, located south of Vienna. Right: Again the strongest radar intensities showed a skewed behavior.

Further application examples, as well as additional information on the project are available from our project webpage [1].

5. Conclusions and Future Work

We have presented a novel technology for the interactive visual analysis of weather information, which allows interactive exploration of complex relations in data coming from several different sources. Linked views are used to show different aspects of the data, whereas the fusion of data from 3D weather radar, measurements from weather stations, and results from forecast simulations in all of the views supports the gaining of knowledge about the current and possible future situations. In the future we plan to integrate further data sources into the system (e.g., satellite data). The next steps will also include the interactive support of the generation of a new layer for the severe weather warning system of meteomedia, called the "Unwetterzentrale" (short: UWZ) [18].

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References

[1] Homepage of the Severe Weather Explorer Project (2006-2008): http://www.weather-explorer.net/
[2] Bill Hibbard, Johan Kellum, and Brian Paul: *Vis5D*. University of Wisconsin-Madison Space Science and Engineering Center (SSEC), available from http://www.ssec.wisc.edu/~billh/vis5d.html
[3] Steven G. Johnson and Jim Edwards: *Vis5D+*. Available from http://vis5d.sourceforge.net/
[4] NCAR Graphics. Available at the National Center for Atmospheric Research (NCAR) from http://ngww.ucar.edu/

[5] Ed Szoke, Herbert Grote, Paula T McCaslin, and Philip A. McDonald: *D3D: Overview, Update, and Future Plans*. Published in the Interactive Symposium on AWIPS, Orlando, Florida, American Meteorological Society, 2002.
[6] Miriam Lux and Thomas Frühauf: *A Visualization System for operational Meteorological Use*. Published in Proceedings of WSCG 1998, pages 525-535, 1998.
[7] Tian-Yue Jiang, William Ribarsky, Tony Wasilewski, Nickolas Faust, Brendan Hannigan, and Mitchell Parr: *Acquisition and Display of Real-time Atmospheric Data on Terrain*. Published in the Proceedings of the Joint IEEE TCVG–EUROGRAPHICS Symposium on Visualization (VisSym 2001), pages 15-24, 2001.
[8] Thomas Gerstner, Dirk Meetschen, Susanne Crewell, Michael Griebel, and Clemens Simmer: *A Case Study on Multiresolution Visualization of Local Rainfall from Weather Radar Measurements*. Published in the Proceedings of IEEE Visualization 2002 (Vis 2002), pages 533-536, 2002.
[9] Kirk Riley, David S. Ebert, Charles Hansen, and Jason Levit: *Visually Accurate Multi-Field Weather Visualization*. Published in the Proceedings of IEEE Visualization 2003 (Vis 2003), pages 279-286, 2003.
[10] Helmut Doleisch, Martin Gasser, and Helwig Hauser: *Interactive Feature Specification for Focus+Context Visualization of Complex Simulation Data*. Published in the Proceedings of the 5th Joint IEEE TCVG–EUROGRAPHICS Symposium on Visualization (VisSym 2003), pages 239-248, 2003.
[11] Helmut Doleisch: *Visual Analysis of Complex Simulation Data using Multiple Heterogeneous Views*. PhD thesis at the VRVis Research Center and the Institute of Computer Graphics and Applications at the Vienna University of Technology, Vienna/Austria, 2004.
[12] Stephan Schmidt, Oliver Schögl, Roland Kirchberger, Helmut Doleisch, Philipp Muigg, Helwig Hauser, Markus Grabner, Alexander Bornik, and Dieter Schmalstieg: *Novel Visualization and Interaction Techniques for Gaining Insight into Fluid Dynamics in Internal Combustion Engines*. Published in the Proceedings of the NAFEMS Worldcongress 2005.
[13] Helmut Doleisch, Michael Mayer, Martin Gasser, Roland Wanker, and Helwig Hauser: *Case Study: Visual Analysis of Complex, Time-Dependent Simulation Results of a Diesel Exhaust System*. Published in the Proceedings of the 6th Joint IEEE TCVG–EUROGRAPHICS Symposium on Visualization (VisSym 2004), pages 91-96, 2004.
[14] Robert S. Laramee, Christoph Garth, Helmut Doleisch, Jürgen Schneider, Helwig Hauser, and Hans Hagen: *Visual Analysis and Exploration of Fluid Flow in a Cooling Jacket*. Published in the Proceedings of IEEE Visualization 2005 (Vis 2005), pages 623-630, 2005.
[15] Helmut Doleisch, Philipp Muigg, and Helwig Hauser: *Interactive Visual Analysis of Hurricane Isabel with SimVis*. Published as Technical Report TR-VRVis-2004-058 at the VRVis Research Center, 2004.
[16] Helwig Hauser, Helmut Doleisch, and Philipp Muigg: Interactive Visual Analysis of Hurricane Katrina with SimVis, VRVis Research Center, available from http://www.vrvis.at/simvis/cases/Katrina/
[17] Johannes Kehrer, Florian Ladstädter, Philipp Muigg, Helmut Doleisch, Andrea Steiner, and Helwig Hauser: Hypothesis Generation in Climate Research with Interactive Visual Data Exploration. Published as Technical Report TR-VRVis-2008-006 at the VRVis Research Center, 2008. Currently in submission.
[18] Homepage of the "Unwetterzentrale" (UWZ) for Austria, the severe weather warning system by meteomedia. Available from http://www.unwetterzentrale.at/