Where Weather Meets the Eye – A Case Study on a Wide Range of Meteorological Visualisations for Diverse Audiences

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Abstract. Sophisticated visualisation enables experts as well as lay persons to extract knowledge from complex data. This is particularly true for visualising the massive amounts of data involved in meteorological observations and simulations. These are of interest to scientists, to forecasters, and to the general public. The paper presents and discusses a range of solutions for meteorlogical visualisation. Topics covered include systems for the production of TV weather forecasts, for the analysis of simulation output by experts, for personalised weather information in the Web, and for meteorological visualisation using Virtual Studio and Augmented Reality technology.

1 Introduction

The visualisation of meteorological data [3] is the last element in the pipeline of meteorological data processing. Only sophisticated visualisation enables the forecaster, the researcher, or the general public to understand complex circumstances [6]. However, users are requesting tailored visualisation tools [2]. While researchers need interactive scientific visualisation, forecasters at the media department are requesting sophisticated TV presentation systems. Private and business customers must be supplied with easy to understand, sometimes even entertaining, and probably personalised presentations of the weather data.

Fraunhofer IGD and the German Meteorological Office (DWD) jointly collaborate in weather visualisation since early 1992 [4]. The TriVis system for professional TV production is in daily operation at several TV stations since 1993. It offers animated 2D weather maps or 3D scenes. In order to fully exploit the results from the numerical weather prediction (NWP) forecasts and observations, a 3D system called VISUAL has been developed. It is installed in the operational environment of DWD's central forecasting office. VISUAL is a scientific visualisation system which is used by both forecasters and researches to "understand data". In order to supply the general public with tailored information, IGD has developed a system called Weather on Demand (WxoD) which is on-line in the WWW since 1998. The WxoD software is based on Java, JavaScript, VRML, and CGI-Scripts. Upon request it creates images and animations for customer definable locations, areas and time intervals. A user-database can be used to personalise the system. Virtual studio technology helps to achieve appealing, cost effective, improved TV weather products. Augmented Reality can also lead to additional insight and ease of use of weather visualisation.

2 Professional TV production

Modern numerical weather prediction models offer rich information full of dynamics that is of high interest to the television spectators. In the early 90s when the traditional weather production was mostly done by hand at the TV station with the help of weather faxes, it could not convey this growing information content anymore. Direct and highly automated access to the full model output was necessary. This directly led to the development of the TriVis system which can produce animated 2D weather maps (fig. 1) or 3D scenes (fig. 2, 3). TriVis can show clouds with snow precipitation animated over time with the snow accumulating on the ground and melting away during the following hours in a single smooth forecast video (fig. 2).

TriVis stands today as a fully or semi-automatic production environment for broadcast-ready weather forecast videos and is well suited for the generation of on-line weather products or cost-effective weather show production In addition, it offers the possibility for the interactive manipulation of all visualisation parameters and attributes at all times during the production process.

The very flexible import functionality of all design relevant objects like fonts, maps, or weather symbols allows an individual design for every television station. When desired, complex visualisation functions and effects algorithms generate attractive and sometimes even spectacular computer graphics.

The two-dimensional presentation offers mainly clear and easy-to-perceive weather maps, while the three-dimensional modules bring a high realism together with necessary abstraction. TriVis smoothly integrates into existing production environments at television stations or weather services.

TriVis can process many meteorological data types. Satellite images, radar data, any scalar data (e. g., temperatures, precipitation amounts, snow heights, UVB, or wind speeds), and multivariate cloud information can be imported from observations or numerical weather prediction models. It also offers a smooth integration of micro animations (e. g., falling raindrops) according to simulated data (e. g., precipitation type and strength) plus the possibility to display animated weather symbols, overlay texts, contour lines, and fronts.

During the complete production process, TriVis offers all standard visualisation techniques plus spectacular 3D effects. The lay audience is considered in each visualisation step. One special feature is certainly that clouds are visualised with advanced fractal functions to use familiar naturalistic cloud objects for easier perception by the visual simulation of clouds [5].

Currently, TriVis itself is installed and running daily at meteorological offices in two countries and at about a dozen TV stations. In addition, America Online gets its daily weather from the TriVis system and many sites on the Internet feature TriVis images or movies with current weather information.

3 Interactive visualisation for experts

Since the mid-90s, new generations of NWP models have made effective interactive 3D visualisation eminently important. Local effects and also larger simulated complex weather structures can be understood much faster and better if all spatial dimensions can be directly controlled during the visualisation process.

VISUAL allows the highly interactive and combined visualisation of direct model output, historic or experimental model run data, observation values, and arbitrary curvilinear volume data. In addition to this support of data analysis, the observation of a numerical model's behaviour or the comparison of predicted and measured values are possible to gain additional insight. All these methods can be applied to different simulation models and arbitrary data sets at the same time (see fig. 4 and 6).

One main feature are the accurate computations on the original model's data grid (fig. 5) for the generation and presentation of all visualisation objects. They are generated in the precise coordinate system of the numerical weather prediction model (computational space) before being displayed. Within VISUAL, time is considered as an equally important fourth dimension of the data and treated by analogy with the transformation of all spatial information.

In order to visualise new parameters, a user with programming skills can write a plug-in to create, e.g., the Richardson number, the relative humidity, the cloud cover, the pseudo-potential temperature, or the potential vorticity on the fly.

VISUAL is installed at the central forecasting office of the DWD in Offenbach. VISUAL is considered as a powerful 3D visualisation tool to investigate NWP data. In research it is already accepted as an effective tool to visualise the results of model development, especially when doing non-hydrostatic modelling. Interpolation is avoided as much as possible, and so the visualisation is done on the model's grid, and the result is transformed to the current map projection for display. High-quality rendering is one of VISUAL's strong features. Therefore, a sophisticated contouring package has been implemented (fig. 7) that offers both hardware colour shading and the possibility to do solid contours with splines. Cutting planes can be dumped in various pixel and vector formats.

In contrast to the mentioned NWP models, the new Global Model of DWD is best visualised on a sphere. Flexible, interactive visualisation of this data can be done with the ISVAS visualisation system (see fig. 10).

4 Personalised Web access to weather data

While TriVis fulfills the high demands of daily TV broadcast services and VISUAL offers first-class interactive visualisation for researchers, the special needs of individual on-demand weather visualisation for lay persons are met by the WxoD system. Due to the broad availability of powerful Internet technology, new ways of interactive personalised weather information can be realized to the benefit of both private and business customers. For a general discussion of possible distribution schemes of Web-based visualisation see [11], one example of such a service is described in [9].

In a joint project with the German and Swedish meteorological offices (DWD and SMHI), IGD has realized Web based meteorological products. Here, distributed visualisation is used to deliver a variety of meteorological information to many recipients with various client platforms across the Internet. This requires a range of different solutions utilizing HTML, VRML, CGI, JavaScript and Java technology.

A number of weather products have been realized, including CityWeather and Meteogram. In CityWeather (fig. 8), the user can select visualisation parameters to see the predicted weather situation at a particular city in 3D. The request is sent to a graphics server executing the TriVis software which produces the appropriate, individual image according to this request, which then is sent back to the customer. Thus, high quality images can be tailor-made disregarding the client hardware. For the Meteogram (fig. 9), on the other hand, raw data is sent to the client and visualised locally using Java. This gives the user full control over the visualisation process, resulting in high quality 2D-graphs. The different Web-based visualisation solutions which were realized for Weather on Demand implement a range of distribution schemes for different tasks: low or medium bandwidth connection, computation on server or on client.

Further discussions, including personalisation by means of user databases for WxoD and push technology, can be found in [1].

5 3D Weather in the Virtual Studio and in outdoor scenes with Augmented Reality

For the IFA'97 exhibition in Berlin, a first broadcast of three-dimensional weather forecast scenes from a virtual studio was prepared and implemented. DWD's data, the design and broadcast experience of the Hessischer Rundfunk TV station, and the weather visualisation expertise of Fraunhofer IGD made a perfect match for this pioneer project. The TV presentation of weather forecasts from within a virtual studio offers many important advantages. Apart from the significantly lower production costs, there are now many new possible ways and forms of presenting the weather. The weather of tomorrow can be happening today inside or around the studio. At the exhibition, we were able to fully integrate weather in a virtual studio in a world premiere. During the exhibition, weather forecasts produced at the IFA with sophisticated technology were broadcast all over Germany in the ARD TV channel daily (fig. 11). The basis of this successful work was the TriVis system with its extensive 3D weather capabilities.

Augmented Reality (AR) will become an alternative to the conventional techniques of desktop and VR environments for applications where scientific visualisation is needed in a real environment, of course the reuse of conventional, approved scientific visualisation methods in Augmented Reality systems is a must, but first they have to be evaluated and possibly adapted for the new, special demands of AR. Still, only a few AR-based scientific visualisation systems have been realized so far [7][8].

In the field of AR for visualisation, we currently concentrate on two main aspects [10]. Firstly, since AR requires the visualization software to run on *portable* computers, it is necessary to minimize the system's resource consumption. Secondly, we believe that the visualisation techniques will have to be adapted for the usage in AR, e.g., in order not to cover all of the real environment with augmented visualization objects.

But how can meteorological visualisation benefit from AR? The latest numerical weather simulation model developed by DWD is called "Lokalmodell". It scales the horizontal simulation mesh size down to 2.5 km. This makes it possible to visualise the forecast data directly corresponding to the real terrain where the specific weather situation is going to happen. We chose the Feldberg mountain close to Frankfurt to show the next day's horizontal wind direction. We used local terrain data for computing the occlusion of the environment with the augmented objects. The example in fig. 12 suggests that in an outdoor Augmented Reality application the user should consider to use a constant icon size, since a constant size can be one of few remaining depth cues to perceive his real distance to the icon position. Still it can be an advantage to additionally use an artificial depth cue, as demonstrated in the same figure, where a vertical red line cutting the terrain shows the true spatial position of two arrows. If we compare this image to one without vertical red line, we realize the need of "second-order visualisation objects" in Augmented Reality, which do not visualise any value themselves but only help the observer understand the meaning of the actual visualisation. This is similar to auxiliary lines etc. in classical desktop visualisation.

AR is a new, very promising technology for a new class of applications of scientific visualisation. In some cases the known Scientific Visualisation techniques have to be modified and adapted to the special demands of AR.

6 Conclusion

With appropriate tools to process and visualise large volume multiple data sets, it is possible to exploit the inherent information. There are many areas, like aviation meteorology and local scale problems, where animated 3D visualisation is indispensable to understand the nature of the underlying processes. VISUAL will be further developed into an application that allows to effectively support the forecaster during his daily work. Concurrently, consumers of weather information demand better products with appealing graphics that convey more meteorological information in an intuitively understandable way. This must be possible via broadcast channels and increasing use of virtual studio technology or through interactive on-demand applications with individual and tailored forecasts based on WxoD technology. Another emerging technology, namely Augmented Reality, will also be of great benefit in a number of applications.

Next generation numerical weather prediction models simulate very small-scale physics on fine grid meshes that result in extremely large data sets. As the TriVis system demonstrates, simple cloud animations that contain mainly the knowledge about 3D humidity, temperature, and wind fields can compress quite diverse data sets in an intuitively understandable way. Therefore, the future of visualisation lies not only in the depiction of large amounts of 3D, 4D, or 5D data. It rather requires also an intelligent and condensed postprocessing for exploration and presentation. We are working on doing just that for a continuing development of visualisation software where weather meets the eye.

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