3D VISUALISATION IN DAILY OPERATION AT THE DWD

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Summary: Sophisticated visualisation enables scientists as well as forecasters to extract knowledge from complex data. The DWD and the Fraunhofer IGD are jointly developing visualisation systems that allow to understand and present data. The necessity to use 3D visualisation is pointed out. First experiences with 3D visualisation in the context of DWD's visualisation systems are described.

1. MOTIVATION

The visualisation of meteorological data is the last element in the pipeline of meteorological data processing. Only sophisticated visualisation enables the forecaster or the researcher to understand complex circumstances. Over the last decade we have seen an enormous increase in data volume. With DWD's new model generation which we expect to be fully developed by the year 2000, we will see an increase in data volume that will be almost a thousand times higher compared to the forecast models we were running during the eighties. It is not only the increased horizontal and vertical resolution that we have to consider, it is also the availability of higher temporally resolved data. Furthermore, we see new parameters, like the liquid water content, and complex physics. Non-hydrostatic models can only be visualised meaningfully with a 3D system. Besides sophisticated 3D visualisation and animation there is a need to reduce the complexity of the problem. There should be methods to present data intelligently - to condense information. Our internal and external customers are requesting tailored visualisation tools. While researchers need interactive scientific visualisation, forecasters at the media department are requesting sophisticated TV presentation systems.

2. OVERVIEW

At the DWD, different visualisation systems are in use. Forecasters are currently working with the Meteorological Application and Presentation System (MAP). MAP allows to visualise and animate imagery, observations, and Numerical Weather Prediction (NWP) data in 2D (*Kusch*, 1994). The MAP system also manages different databases in a client/server environment. Figure 1 shows the main visualisation window of MAP, depicting a Meteosat image, differences between observed and forecasted spot values of maximum temperature, and a forecast of the pseudo-potential temperature.

In order to fully exploit the results from the NWP forecasts and observations, a 3D system called VISUAL is developed. It is currently tested 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".

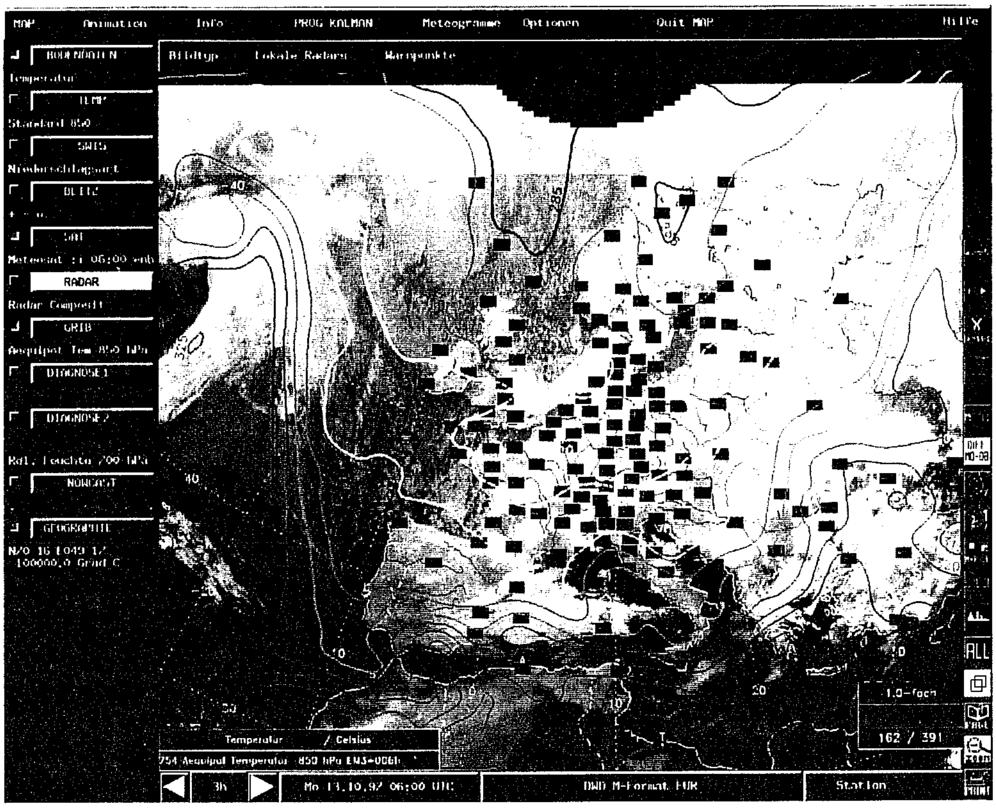


Figure 1: MAP

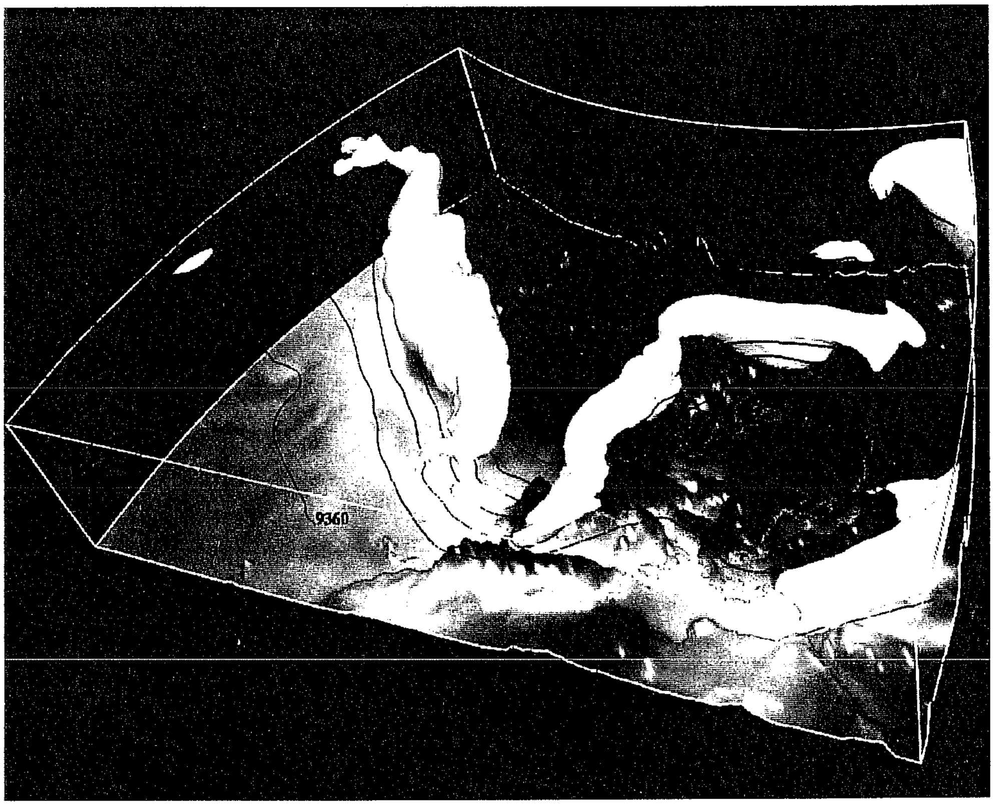
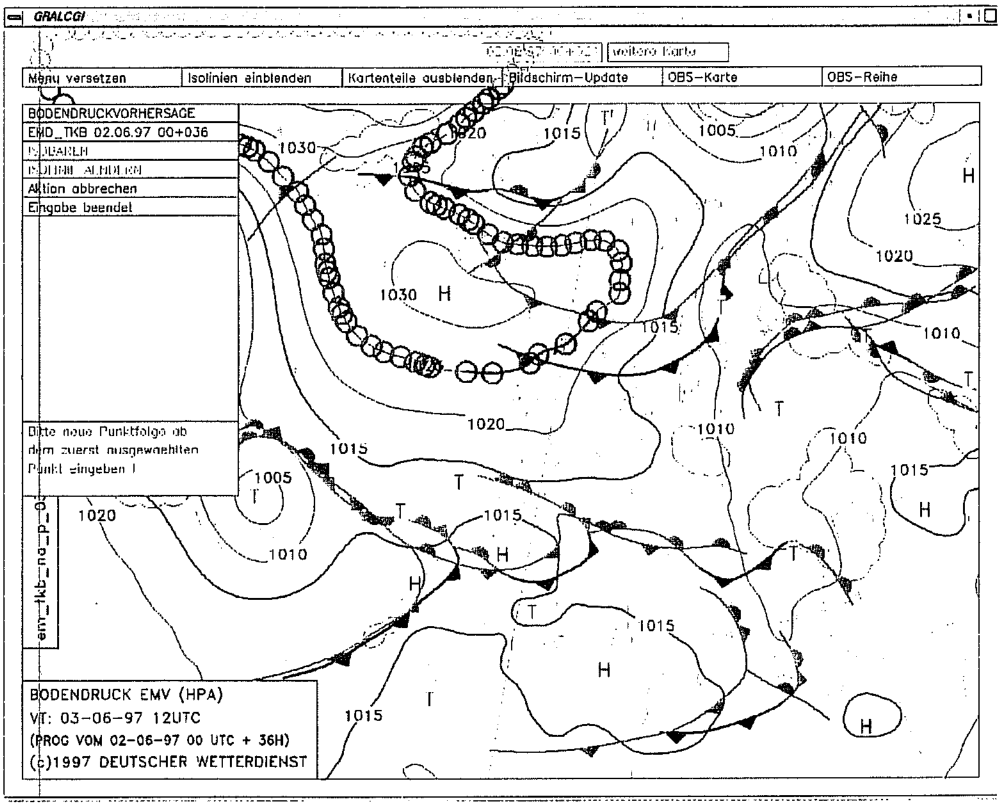


Figure 2: VISUAL



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dem zuerst ausgewaehlten
Punkt eingeben !

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(c)1997 DEUTSCHER WETTERDIENST

Figure 3: IGS

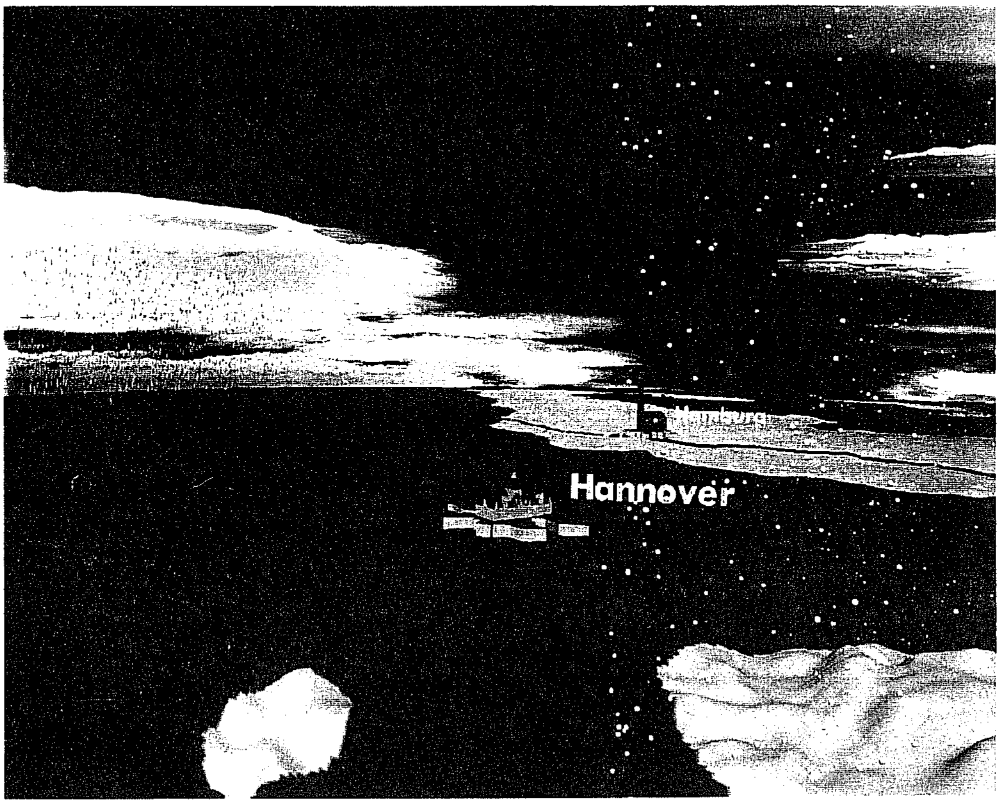

Figure 4: TriVis

VISUAL fits in the overall concept of DWD's different visualisation components. Therefore it accesses the MAP databases. Figure 2 shows a forecast of the "Europa-Modell": the temperature at the lowest model level together with the 45m/s iso-surface of the windspeed and the geopotential height at the 300 hPa pressure level. If there are discovered large differences between NWP-forecasts and observations, the forecaster has to modify the numerical forecast. At the DWD, the Interactive Graphical System (IGS) is used to revise automated forecast products (*Koppert*, 1991). The IGS allows to modify gridded fields as well as graphical objects like, for example, iso-lines and fronts. Figure 3 shows one configuration, the surface forecast chart, where iso-lines and fronts are in an edit status.

The result of the forecasters' work has to be presented to the public. In order to communicate the results to TV audiences, we use the TriVis system of the DWD (*Koppert*, 1993). It allows to visualise and animate NWP data in an intuitively understandable way. Figure 4 shows a 3D view of Northern Germany with fractal clouds, areas with snow and rainfall, and snowcover mapped on the earth's surface. Snowcover is changing dynamically during animation.

The above described systems are designed for experts. In order to supply the general public with tailored information, we have already developed a system called Weather on Demand (WxoD®). The WxoD® software creates on request images and animations for customer definable locations, areas and time intervals. The result of the query are meteograms, images, animations, and 3D flights/views. They can be viewed with any WWW browser.

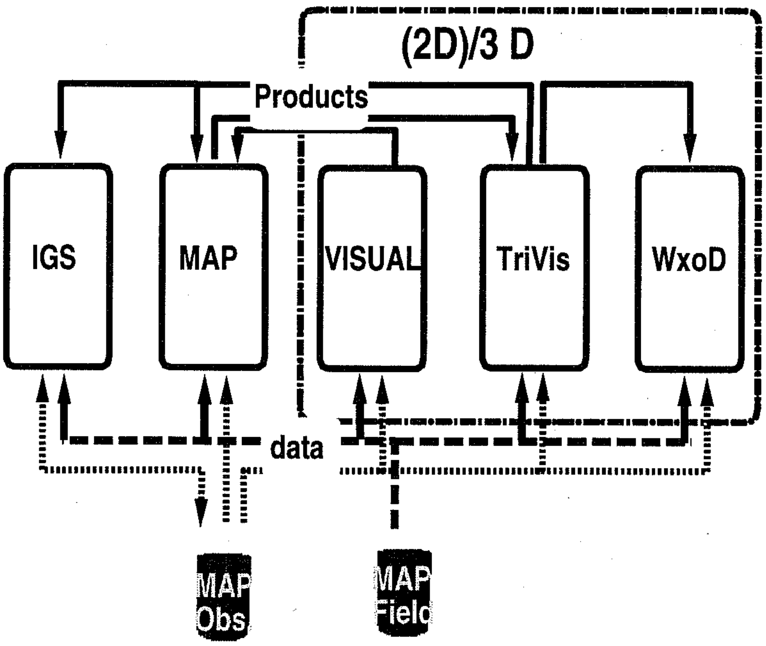

Figure 5: Overview of 3D visualisation systems at the DWD

Figure 5 shows the general architecture of the mentioned systems. All are accessing the MAP databases. The IGS is allowed to store modified forecasts only. There is an exchange of products between the systems. VISUAL acts as a visualisation server and supplies MAP with vertical and horizontal cross-sections of NWP forecasts. TriVis creates MPEG videos for MAP and visualises requests from the WxoD® system. MAP creates analyses from current observations and makes the resulting grids available to TriVis.

3. SYSTEM ARCHITECTURE

At the DWD, all three-dimensional visualisation work is accomplished with the two systems TriVis and VISUAL. Together with the availability of affordable graphics hardware for the accelerated rendering of polygonal objects, the Fraunhofer-IGD and the DWD have intensified their cooperation since 1992 with joint efforts regarding both systems.

3.1 **TriVis vs. VISUAL - Why Two 3D Systems?**

Generally, when designing single visualisation algorithms or even more when building larger systems, there must always be considered the complete context of the whole visualisation process. This includes not only the data types, but also the purpose of visualisation and the targeted audience (*Schröder*, 1995). In the case of the three-dimensional visualisation of meteorological data at the DWD, very similar data are visualised for very different purposes for very different audiences. The following table outlines the most different and contrary requirements for TriVis and VISUAL:

TriVis (3D television weather visualisation)	VISUAL (interactive 3D met. visualisation)
Maximum flexibility in visualisation techniques	Standard and common visualisation techniques
Highly automated visualisation production	Highly interactive visualisation for exploration
Main target audience: lay persons	Main target audience: meteorologists
Focus on broadcast quality rather than accuracy or high frame rates	Focus on interactivity (high frame rates) and accuracy rather than nice images
Interfaces to modelling tools and virtual studios	Interfaces to standardised met. databases

In addition to the diverse requirements, there are also fundamentally distinct application scenarios for both employment fields of scientific visualisation. The television weather presentation application needs a very effective and secure routine production environment to compute many forecast animations for different customers on a daily basis. On the contrary, the interactive meteorological visualisation is applied to gain insight into the large data sets and to produce ideas about the investigated weather situation by being a flexible analysis tool for data exploration. This led to the decision to clearly separate the development of a visualisation system for each application scenario.

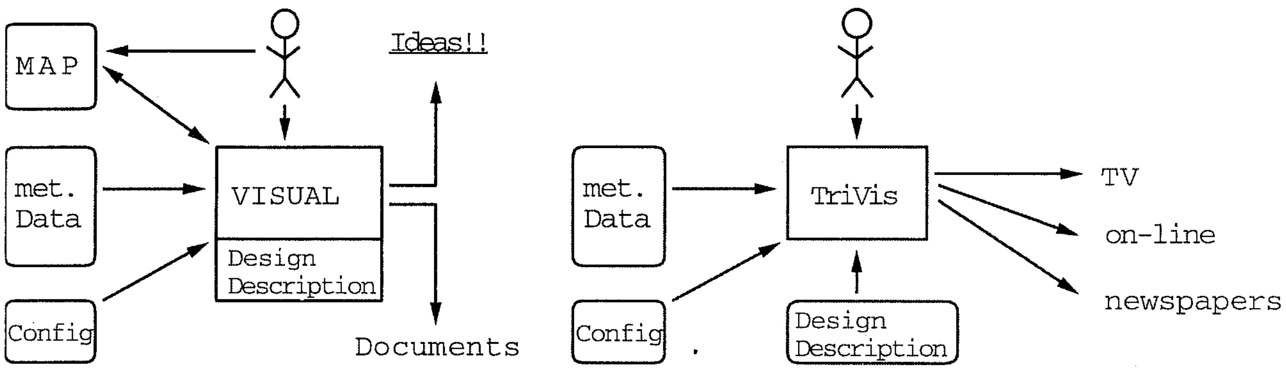

Figure 6: Fundamentally different application scenarios for VISUAL and TriVis

3.2 System Design

The separate visualisation components for both specific tasks were designed to run as independent complete turnkey systems, namely TriVis and VISUAL. However, their common visualisation, interface, and utility functions are stored in libraries utilised by both components. This allows to gain the maximum benefit from two separate tailored solutions while development efforts are reduced to the necessary minimum through code sharing.

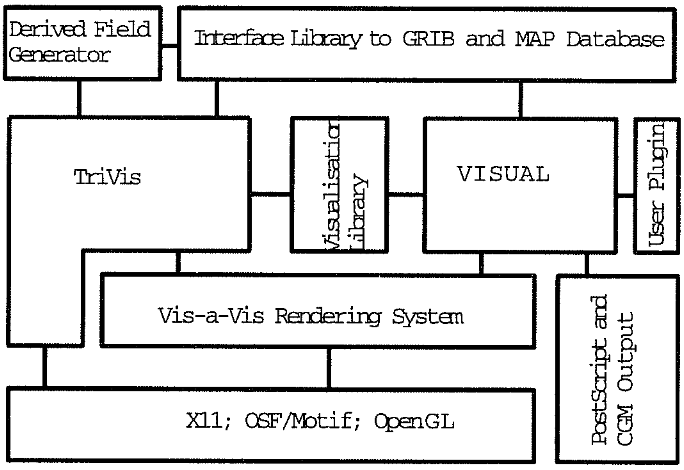

Figure 7: Overall system architecture for TriVis and VISUAL

A high degree of flexibility is achieved by providing open interfaces to plug in user functions or new visualisation techniques without the necessity of having the core program's code available. In addition, some platform independence was obtained by building the software solely on the X Window System, OSF/Motif, and the high-performance Vis-a-Vis rendering system developed at the Fraunhofer-IGD (*Encarnação*, 1992). This rendering system offers OpenGL, PEX, and IrisGL support as well as two volume rendering algorithms.

4. VISUAL

Since the mid-90s, new generations of NWP models have made effective interactive three-dimensional visualisation eminently important (*Hibbard*, 1989). 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.

After a thorough evaluation of the visualisation tools available on the market (including application builders like AVS or the IRIS Explorer and turnkey systems like VIS5D (*Hibbard*, 1991), the DWD and the Fraunhofer-IGD decided to customly build a tailored special solution that matches all important requirements like the effective and implicit handling of hybrid and dynamic model coordinates in different computational spaces.

4.1 **General**

VISUAL allows the highly interactive and common visualisation of direct model output, historic or experimental model run data, observation values, and arbitrary curvilinear volume data. Thus, any observed or forecast weather situation can be analysed in an investigative manner. 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.

One main feature are the accurate computations on the original model's data grid for the generation and presentation of all visualisation objects. They are first generated in the precise coordinate system of the numerical weather prediction model (computational space), brought into world coordinates for rendering only just before displaying, and, finally, brought into screen coordinates. 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. This allows to treat the meteorological data as information in a five-dimensional space with the three spatial axes, time as the fourth, and the different meteorological parameters as the fifth axis.

The basis for all visualisation functions is an efficient internal data handling that builds an ideal compromise between interactive visualisation and the requirements for little memory consumption for small desktop graphic workstations. The optimum solution in this case was a hybrid composition of sorted lists and array fields that match the special requirements of meteorological data sets where values are scattered over time and parameter space but can be easily indexed in their three spatial dimensions.

4.2 **VISUAL's Visualisation Techniques**

In order to analyse the possibly complex combination of different models, parameters, and observation sources, all the following visualisation techniques can be applied commonly or alternatively to the meteorological data: **model surfaces** with colour mapping and/or contour lines; arbitrary vertical and/or horizontal **cutting planes** with colour mapping and/or contour lines; **wind arrows** on all possible planes and surfaces with a selection of different standard shape generation methods; **iso-surfaces** of all scalar fields or magnitudes of vector fields; **texts** and/or **weather symbols** for discrete observation stations.

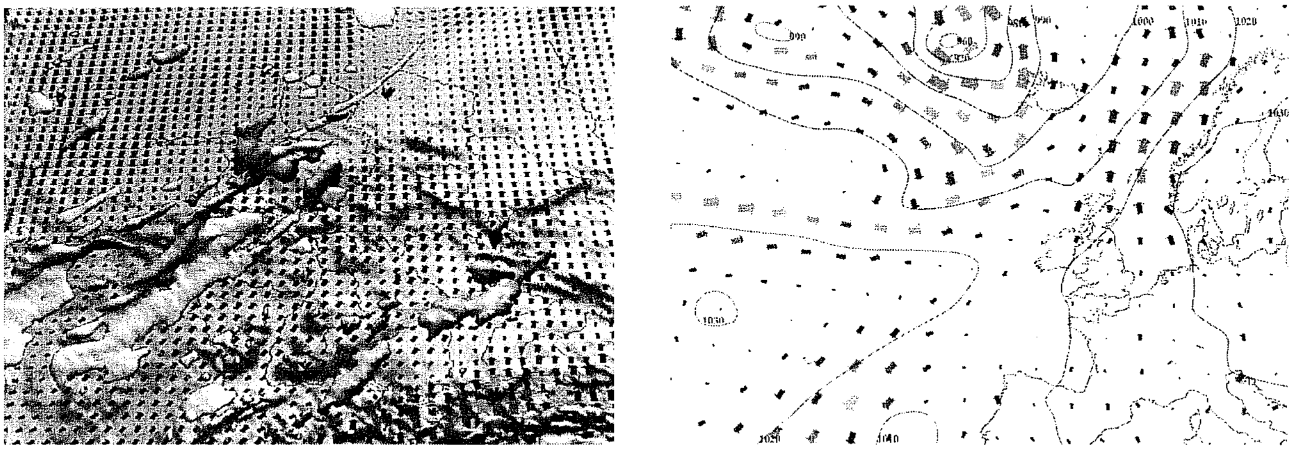

Figure 8: Typical visualisations generated by VISUAL from wind, temperature, liquid water content, and pressure

4.3 **Computations of Horizontal Coordinates**

It is very important to maintain high accuracy during all stages of the visualisation process in order to produce meaningful and non-misleading images. Therefore, when generating all visualisation objects, in VISUAL the horizontal coordinates are obtained through very precise computations in model space.

Afterwards, the visualisation objects are brought into a selected map projection (e. g., polarstereographic projection) and, finally, into world and then by projection or parallel viewing into screen coordinates. This method avoids errors induced by applying visualisation algorithms to data that has been distorted or otherwise turned unprecise by prior map projections.

4.4 **Computations of Vertical Coordinates**

The same applies for the computations of the vertical coordinates. Thus, in VISUAL, all dynamic changes of the vertical coordinates according to changes in the current simulated weather situation are fully considered during the visualisation process as they are in the actual NWP system. The varying pressure in the p-System can be seen as an example:

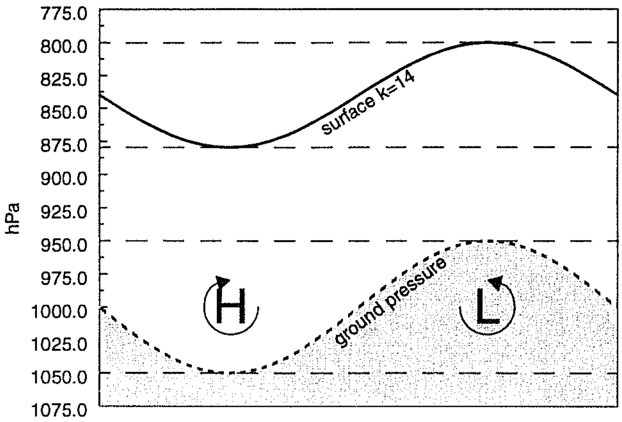

Figure 9: Dependency of a model surface's vertical coordinates on varying ground pressure (p-System)

In the z-System, also temperature and humidity are considered in the computation of the vertical coordinates with the model's grid. This allows to choose between the height representations of all objects against pressure or meters, both computed equally to the algorithms used inside the NWP model itself.

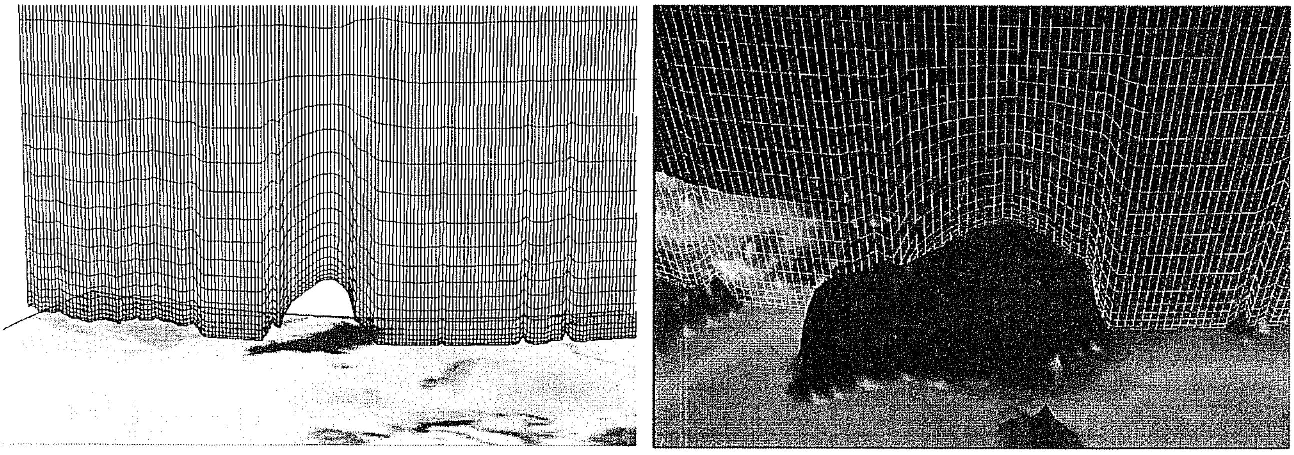

Figure 10: Treatment of the model's vertical coordinates by VISUAL (grid over Greenland)

4.5 **Time Handling**

In meteorology, data time plays an especially important role. Many weather situations cannot be analysed correctly without considering their dynamics. Therefore, inside VISUAL, time is treated as an equally important fourth dimension in the model data. All computations that transform abstract visualisation objects in the model's computational space to the screen for viewing perform the transformation of time by analogy with the transformation of the space coordinates: data time by analogous to object coordinates, world time analogous to world coordinates, and display time analogous to device coordinates.

This method makes it possible to support translations, scalings, and special cases of rotations. The mapping of data time onto discrete single frames is happening analogous to the mapping of continuous data space to discrete pixels. VISUAL gives the user full control over this process by means of an easily understandable user interface.

Since it is very important to absorb the inhomogenities of rendering times during an interactive session with animated data, a constant frame display rate is achieved through a-priori guessing of frame generation times.

The exchange of the time and an arbitrary space axis is a special case of rotation within the four-dimensional space. It can be useful to make dynamic changes or time-periodic data effects visible as geometric properties or colour patterns. All software tools and human perceptual intelligence of analysing spatial patterns can then be applied to dynamic effects.

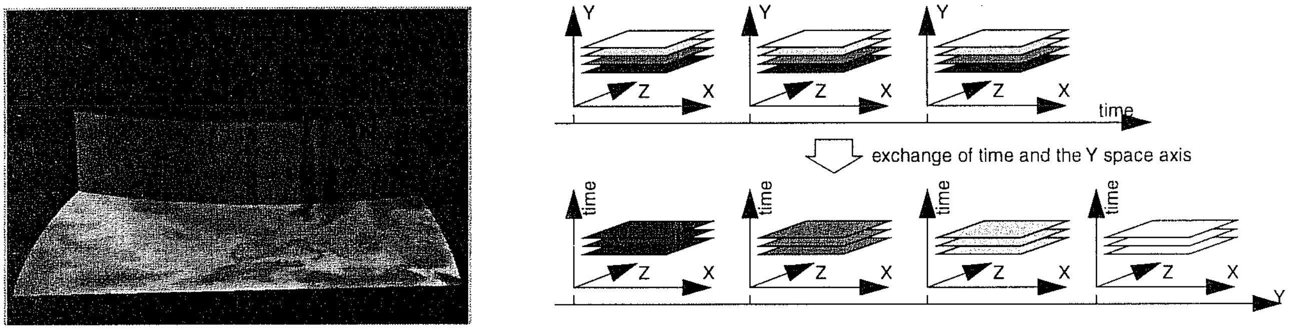

Figure 11: Exchange of time and space axis by VISUAL

5. TRIVIS

Modern NWP 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. 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.

5.1 General

TriVis has been developed since early 1992 and stands today as a fully or semi-automatic production environment for broadcast-ready weather forecast videos. In addition to this fully automatic mode that is useful for the generation of on-line weather products or cost-effective weather show production, TriVis 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. Complex visualisation functions and effects algorithms generate attractive and sometimes even spectacular computer graphics, when desired.

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. The basis for all specially tailored algorithms is the fact that a person looking out of a window from an air-conditioned room can perceive the outside weather quite well just by vision. Images generated by TriVis can always be understood intuitively.

Furthermore, TriVis offers interfaces to common Virtual Studio software systems or 3D modelling tools and image processing systems commonly available on the market and, thus, smoothly integrates into existing production environments at television stations or weather services.

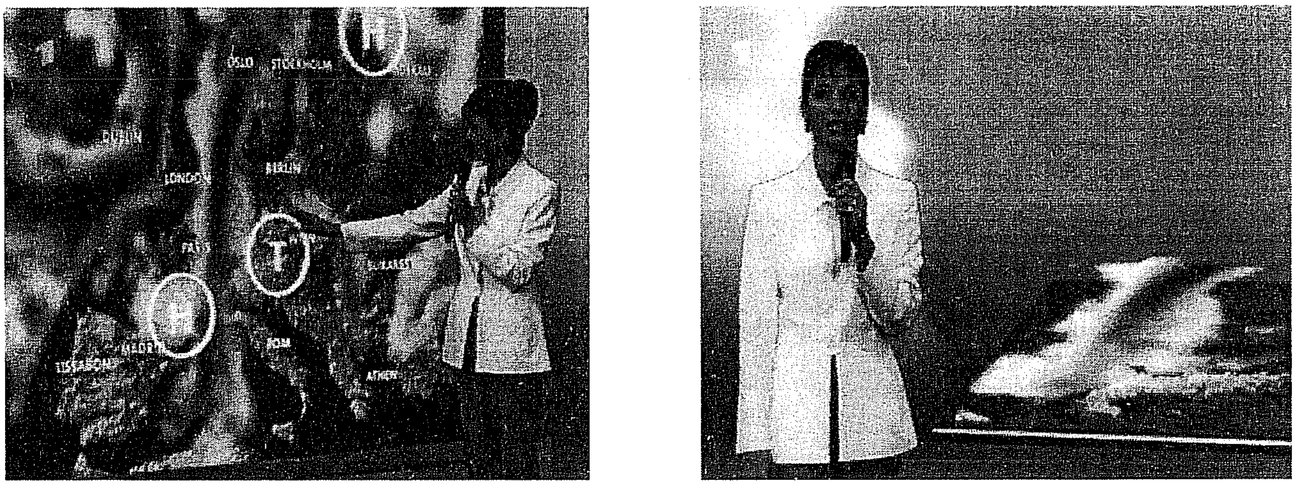

Figure 12: 3D weather geometries generated by TriVis allow full integration into virtual studio systems

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, the lay audience is considered in each visualisation step. One special feature is certainly that clouds are visualised with special fractal functions to use familiar naturalistic cloud objects for easier perception.

5.2 Visual Simulation of Naturalistic Clouds

Fractal functions are widely used for the realistic modelling of natural phenomena (*Mandelbrot*, 1983) like plants, terrain areas, wavy water surfaces, flames, gaseous turbulences, or clouds. Apart from computer animation, fractal clouds also play an important role in scientific visualisation. Since the beginning of the TriVis development, fractal methods have been a fundamental component of the system to convert simulated forecasting data into 2D pseudo-satellite films (*Sakas*, 1993). Clouds and other related weather phenomena can show a lot of condensed weather information in two or three dimensions

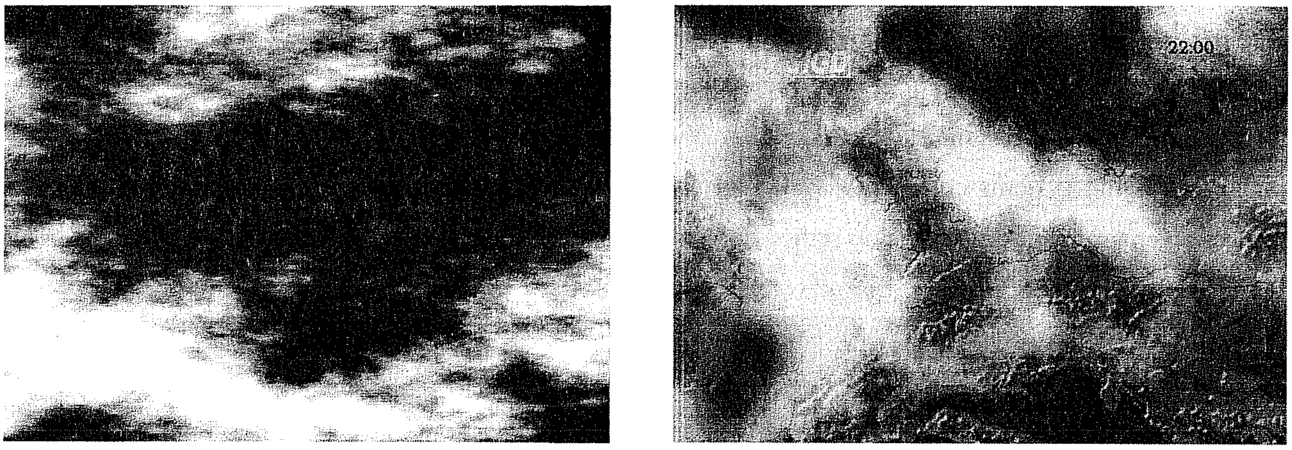

Figure 13: Raw fractal on the left and a visualisation of model output with fractals applied on the right

Within TriVis, a special method is used of to apply fast 2D fractal functions for the generation of realistic two- or three-dimensional clouds that can be rapidly rendered by standard graphics hardware.

Some commercial products use just plain triangulated iso-surfaces to model 3D clouds — with the known severe limitations, especially with the sometimes coarse data grids used in meteorology. Also, 3D fractal functions have been utilized experimentally to create true volumetric clouds (*Cianciolo*, 1993; *Sakas*, 1993), but the computation times necessary for fractal volume generation, ray casting, and hybrid rendering with polygonal objects are usually too long for routine applications.

Within TriVis, the numerical output of NWP simulations is utilized for the parameterization, shaping, and blending of artificial 2D fractal clouds. The results are high-resolution triangulated mesh objects with textures that appear extremely realistic and always preserve the average simulated data values.

From the NWP models seven cloud-specific values are currently extracted for every grid point and used as input to TriVis: cloud coverage, vertical cloud depth, base altitude, contrast, mean density, precipitation type with strength, and simulated lightning activity.

The usually available grid resolution of forecast models is too coarse in relation to the prediction area to be used directly. Prior to further processing, effective smoothing is essential to avoid visible block structures. Neither bilinear nor bicubic interpolation are sufficient since they both interpolate along the axes of the coordinate system, thereby producing visible artifacts. TriVis employs a kind of barycentric interpolation, where the nine neighbours of a sampling point in the original grid are weighed by their Euclidean distance when re-sampling into a finer grid. This interpolation method has been found to be a very good compromise between eliminating coarse grid structures and still preserving local details in the data.

The next task after smoothing the simulated data is to generate realistically looking clouds. TriVis uses fractals as the fundamental artificial cloud synthesis technique to achieve a naturalistic appearance that is familiar to the television spectators and, thus, makes the visualisation perceptually more effective (*Schröder*, 1995).

The most beneficial fractal method is the Rescale-And-Add (RAA) technique introduced in (*Perlin*, 1985) and (*Saupe*, 1988) and extended in (*Sakas*, 1992). The main advantages of RAA are the computational locality (which also makes parallelization straightforward), the structural locality, the low aliasing, the minimal memory requirements, and the automatic adaption to the locally required level of detail. The technique starts with a regular grid of random numbers with zero mean, distributed over the forecast region. These discrete gridpoints are then interpolated by means of linear, cubic, or higher order interpolation to a continuous stochastic function called *noise* or, better, *auxiliary function*.

$$V_H(x,y) = S \times \sum_{k=k_0}^{k_1} \frac{1}{r^{kH}} \mathrm{Aux}(r^{k\mu_x}x, r^{k\mu_y}y)$$

Auxiliary Function (1)

Aux and V_H have a mean of zero. S is a scaling factor for the variation range of V_H. H is the Hurst exponent. r is the lacunarity factor. k_0 and k_1 define the size of the largest and smallest structures. μ_x and μ_y are used to variate the fractal dimension along the x and y direction.

A fractal set (V_H) is defined as the overlap of several appropriately down-scaled copies of the auxiliary function Aux (see eq. 1). Three of the extracted forecasting parameters (cloud density, contrast, coverage) can be mapped onto corresponding fractal parameters to create a visual appearance matching the forecasted values. The structural locality of the RAA method allows independent regional variations of all required parameters.

5.3 Automatic Modelling of 3D Clouds

After extracting the cloud-specific raw data from the simulation models and smoothing their grid values, they are finally merged with the just generated 2D fractal. In this process, the RAA fractal is shaped and blended by the meteorological data. The resulting fractally perturbed data is then appropriately scaled twice to generate the upper and lower shells, while the lower one is also mirrored vertically. Finally, both shell halves are assembled to form the 3D cloud. For fast rendering on standard graphics hardware, the resulting geometries are semi-transparent, grey-coloured, and arbitrarily fine triangle meshes with the cloud textures upon them.

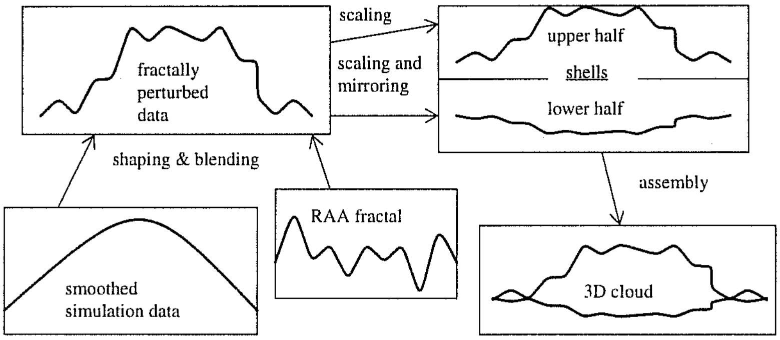

Figure 14: Process of converting fractals into 3D clouds

The distance between the upper and lower shell halves is defined by the vertical depth, and the height of the cloud above the terrain is specified by the base altitude. The contrast regulates the amplitude of the fractal perturbation. Grey value and ground shadow intensity are defined by the specific density combined with the vertical depth determining how much light can pass through the cloud from top to bottom. The coverage influences the fractal granularity and the transparency, especially in the rim areas.

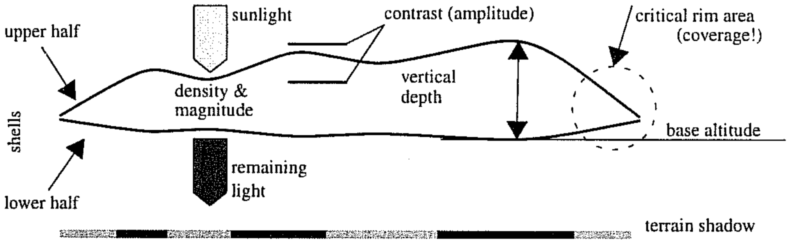

Figure 15: Simulated data mapped onto cloud properties

The techniques and methods proposed above have proven to be ideally suited for the fast generation of very realistic 3D clouds from either simulated meteorological forecast or recorded satellite data.

6. APPLICATIONS

6.1 MAP

MAP allows the 2D visualisation and animation of all data available at the DWD: NWP fields, points (Direct Model Output, Kalman-filtered forecasts, MOS, TAF); surface observations; temps; lighting data; and, finally, imagery (Meteosat, GOES-E, NOAA).

It incorporates modules for road weather forecasting (see figure 16, interactive table contains among other things the forecasted road condition and the road surface temperature), nowcasting applications and tools tailored to the needs of the aviation forecaster.

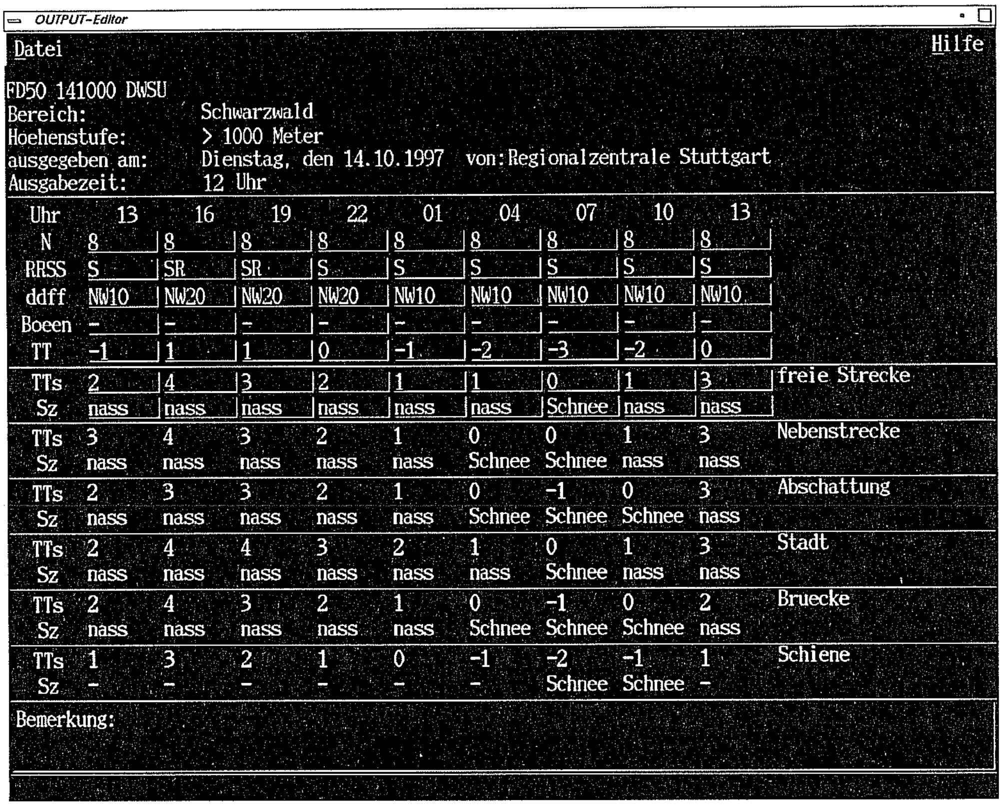

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Figure 16: interactive table with forecasted road condition and road surface temperature

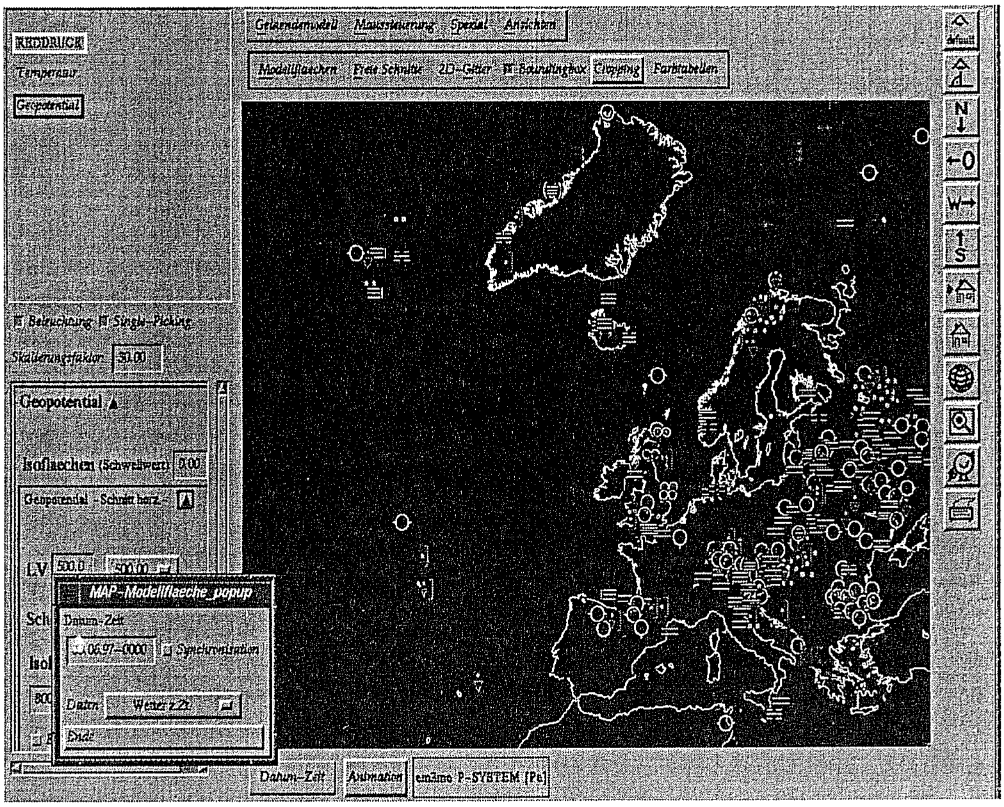

Figure 17: VISUAL's user interface

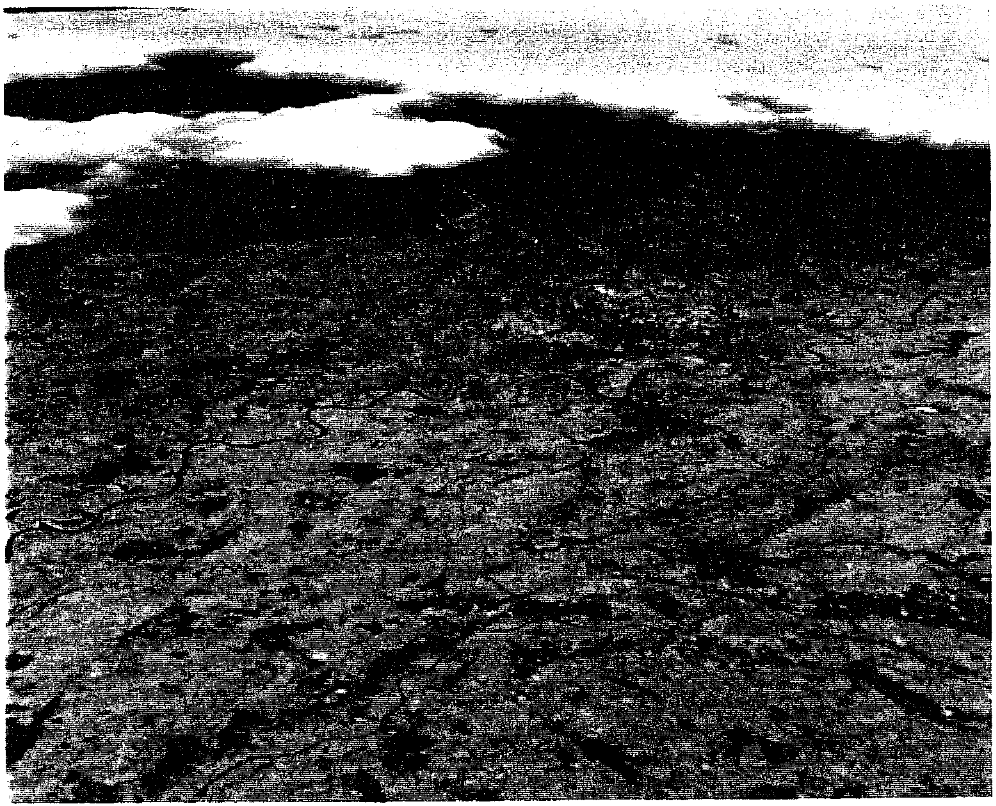

Figure 18: High-resolution terrain with satellite texture and model clouds in TriVis

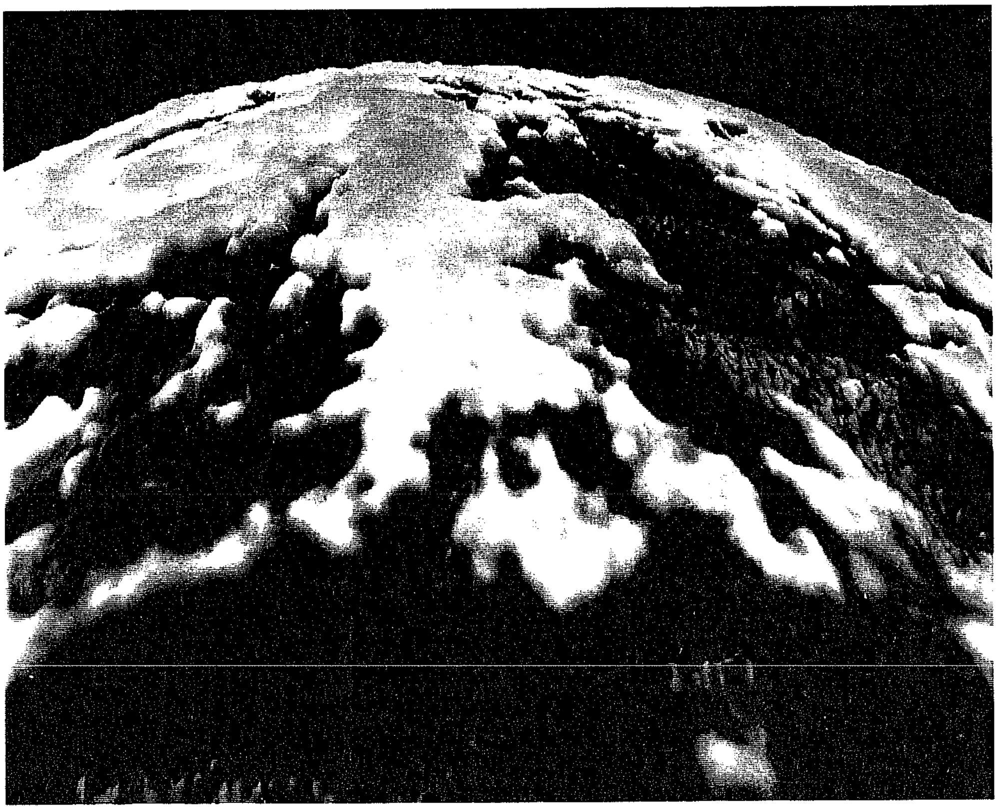

Figure 19: 3D view of Europe with a fractally enhanced Meteosat image created with TriVis

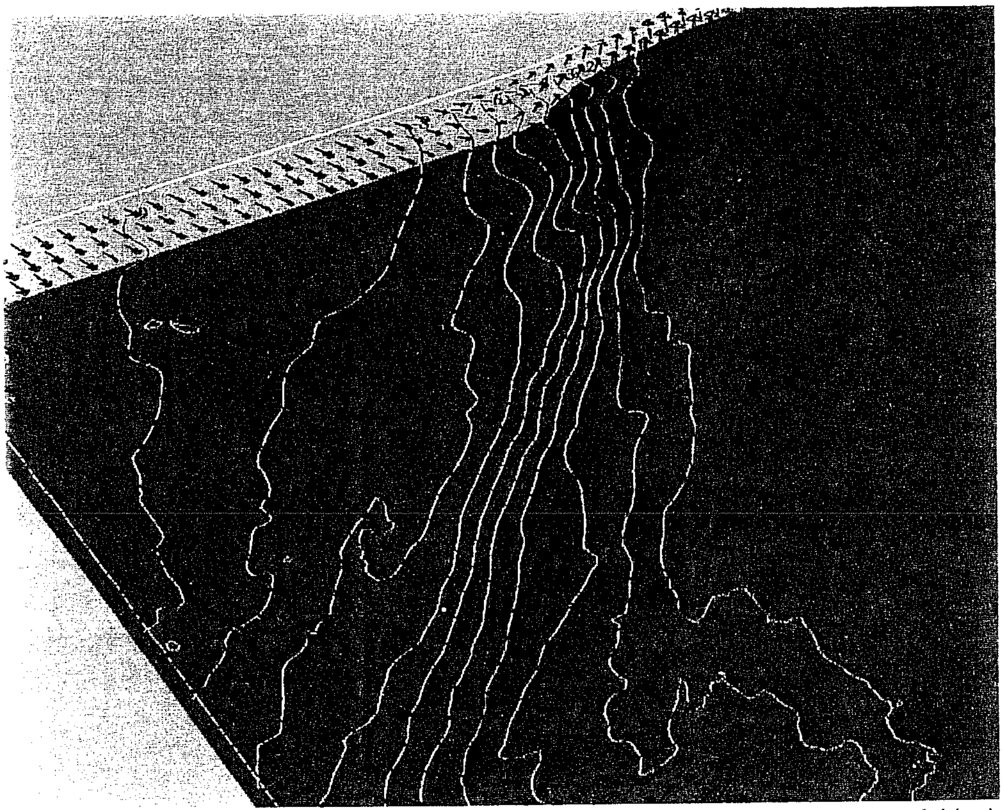

Figure 20: Iso-surface of pseudo-potential temperature (calculated by a user-supplied plug-in) overlaid with iso-lines of temperature and wind-vectors created by VISUAL

Figure 21: Model surface and arbitrary horizontal cutting plane visualised together by VISUAL

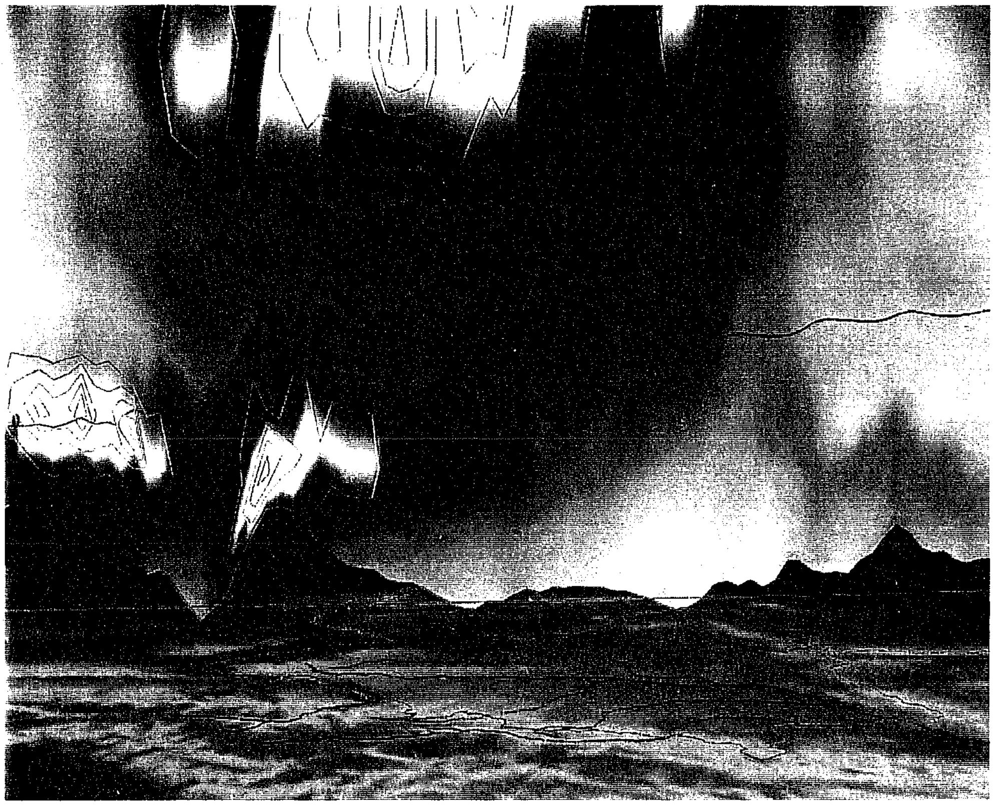

Figure 22: Vertical slice depicting relative humidity, iso-lines of liquid water content, and height of freezing level created by VISUAL

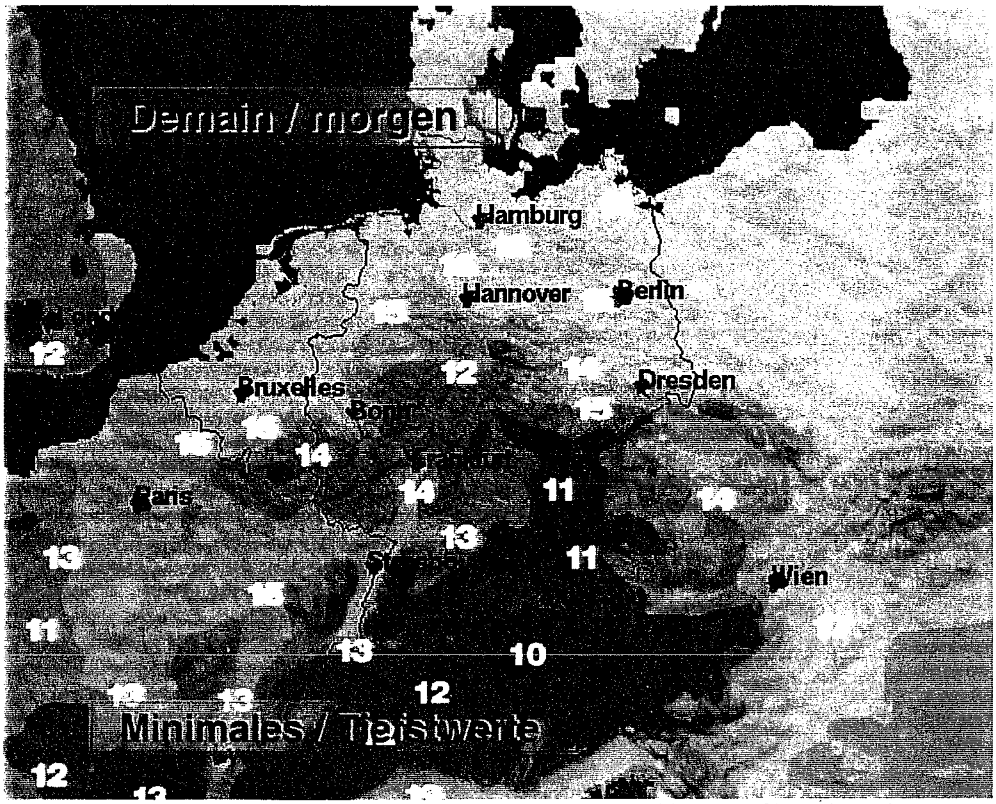

Figure 23: 3D view of Germany with colour-shaded 2 m temperatures and kalman-filtered maximum temperatures at customer-defined locations created by TriVis

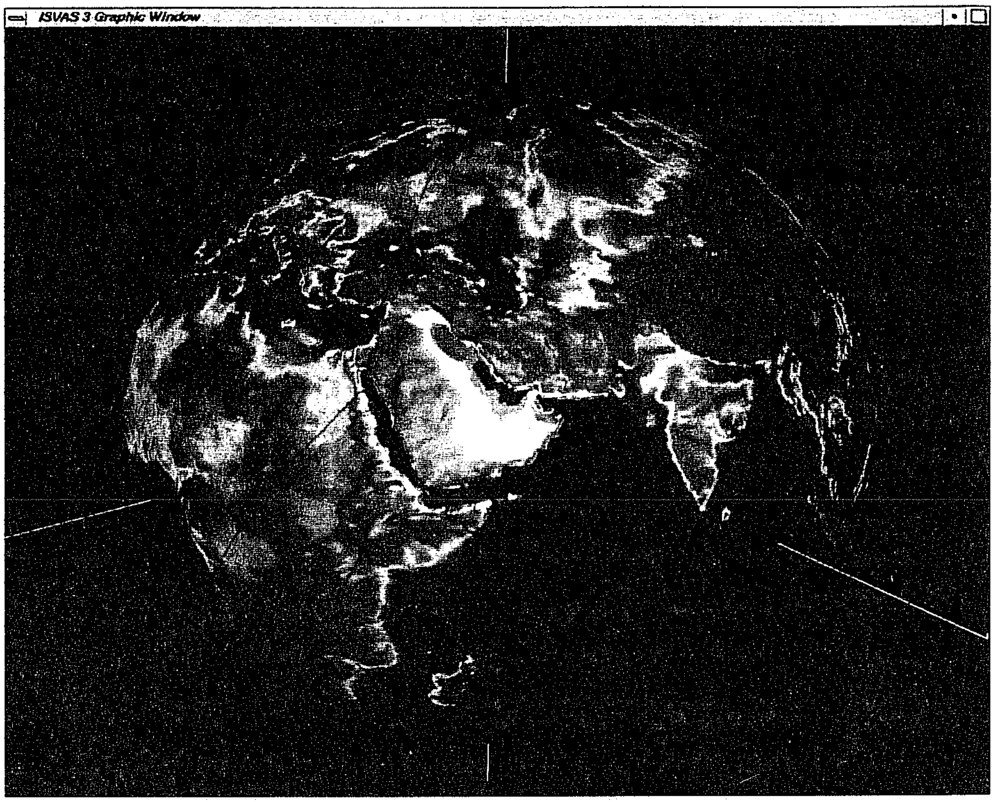

Figure 24: DWD's new Global-Modell visualised with IGD's ISVAS

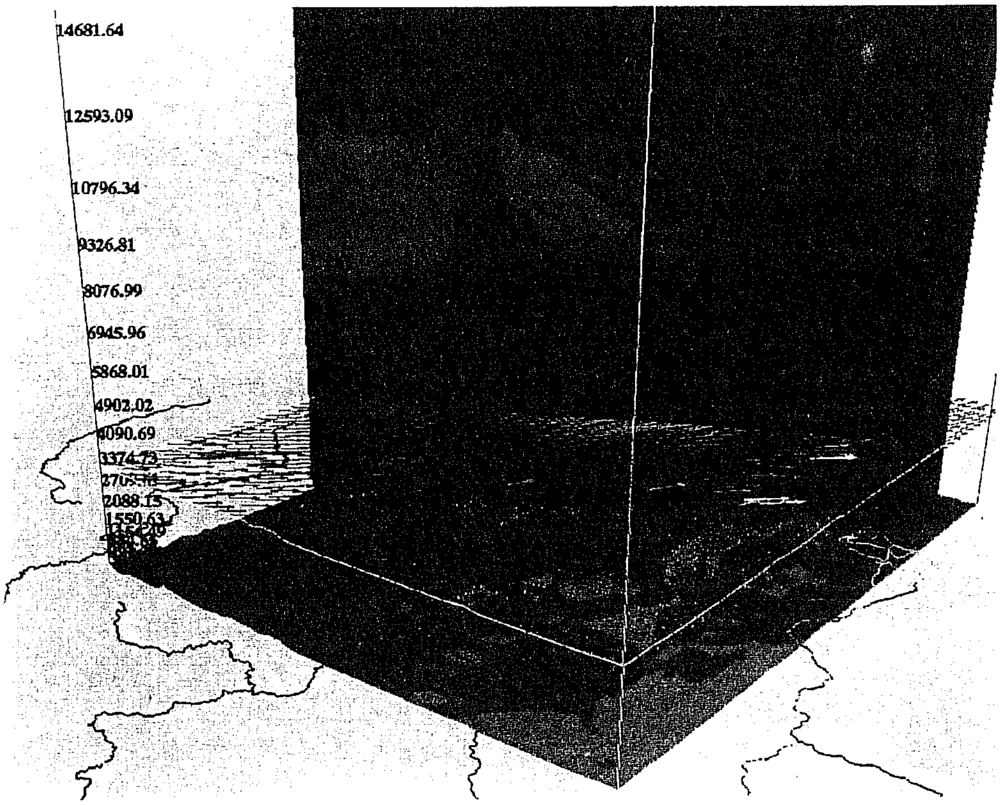

Figure 25: Vertical slice of wind speed generated by the solid contour algorithm

IGS allows to interact with the data on the data level and on the level of graphical objects. Further work focuses on the integration of meteorological applications.

6.2 **TriVis**

TriVis is designed to produce an intuitively understandable presentation of the weather forecast. There is a rich set of tools to achieve the most effective visualisation with respect to the targeted audience. TriVis allows to visualise fields (NWP forecasts and MAP analysis) and point observations/forecasts in 2D and 3D.

Colour mapping in the form of solid or Gouraud colour shading can be used to display scalar parameters like temperature or sunburn index. Figure 23 shows a 3D view of Germany with overlaid spot values of maximum temperature. There is always the possibility to overlay additional information. Text (e. g., numbers), 2D Pictograms/3D objects, 2D pixmaps/3D billboards, iso-lines and fronts can be overlaid and animated automatically or interactively in numerous ways.

Fractal algorithms are used to visualise clouds in 2D and 3D. Figure 18 shows the forecast of DWD's "Deutschland-Modell" (14 km horizontal resolution). In order to supply the necessary context information, TriVis is able to display cities, borders, rivers, and lakes together with high-resolution digital elevation models and surface textures derived from Landsat TM.

Satellite and radar imagery is visualised in 2D or 3D. Realistic depictions of satellite imagery is achieved by applying fractal techniques to the original pixel data. Figure 19 shows a fractally enhanced 3D satellite image, depicting the hurricane Iris over the English Channel.

6.3 **VISUAL**

We have configured VISUAL for the two operational DWD models "Europa-Modell" (EM3MO, 181*129*20 gridpoints) and "Deutschland-Modell" (DM4MO, 163*163*30 gridpoints) as well as for the non-hydrostatic "Lokal-Modell" (LM, 350*350*35 gridpoints). Currently, we are investigating visualisation techniques for the new global model GM_E, which uses a triangular horizontal grid. Figure 24 shows the orography of the GM_E model and depicts the "diamond"-like structure of the grid. This visualisation was done by utilising Fraunhofer-IGD's ISVAS software (*Karlsson*, 1992; *Frühauf*, 1994), that is designed to handle FE and voxel data.

EM3MO, DM4MO and LM forecasts are stored in a database using the GRIB0 or GRIB1 standard. All the necessary coordinate informations are retrieved from the GRIB definition block. It is also possible to supply ASCII files for visualisation. In this case, the 3D coordinates have to be specified explicitly. The vertical coordinate used for display can be pressure or height (z). In the horizontal, we are currently using the stereographic projection. VISUAL handles scalar and vector data. 3D voxel data (radar cubes, cloud analyses from Meteosat) can be processed by explicitly specifying the coordinates of the voxels. Figure 20 shows a coldfront over Northwestern Germany with the iso-surface of the pseudo-potential temperature overlaid with iso-lines of temperature at an arbitrary pressure level and windvectors.

VISUAL allows to display horizontal and vertical slices. In the case of horizontal cutting planes, we have implemented the possibility to display model surfaces and arbitrary horizontal slices together. Figure 21 clearly shows these features. In a z-coordinate system, we are displaying the lowest model layer ranging from 0 to 3100 m together with a horizontal slice at 1000 m. It becomes obvious that the lowest model surface "breaks through" the 1000 m slice in mountainous regions. This is only possible, because VISUAL always uses the original model grid. Vertical cutting planes are implemented along the model axis that needs no interpolation, and along arbitrary definable lines. Due to this concept, VISUAL is open to create time cross sections, which will be realised until summer 1998. Figure 22 shows a cutting plane with colour-shaded relative humidity, iso-lines of liquid water, and iso-lines (0 and -20 °C) of temperature. This is a rough first approach to supply tailored products for aviation forecasters. As already mentioned in chapter 4.2, VISUAL allows to visualise iso-surfaces of scalars. Furthermore, we have implemented a very simple data probing that reads the colour of a selected pixel and displays the original data value very quickly.

In order to facilitate orientation in 3D space, VISUAL allows to overlay borders and rivers on any horizontal or model surface slice as well as to overlay coordinate lines (hPa, hft or m) on vertical slices. Besides the orography of the model, also high-resolution digital elevation models prepared for TriVis can be used. At any time during an interactive session, a parallel projection can be chosen rather than the perspective projection to improve the estimation and comparison of the objects' dimensions.

Parameters that are not available in the standard database can be created during run-time. In this case, the "power user" has to write a plug-in (shared library) on the basis of a supplied template. With this technique it is quite easy to create the Richardson number, the relative humidity, the cloud cover, the pseudo-potential temperature, or the potential vorticity on the fly.

The user interface is grouped around the main visualisation window. There are areas to choose the desired parameter, to define the visualisation techniques, to modify the graphical attributes, to control animation, and to specify view points. Parameters and actions are bundled together by a colour concept that allows to identify the respective parameter.

7. EXPERIENCES

7.1 TriVis

So far, our experience with two TV stations using our 3D modules have shown that completely new editorial concepts are necessary for this type of presentation. The six "golden rules" can be summarized as: do not confuse the viewer; do not integrate too many information elements in the same image; always use a familiar and intuitively understandable depiction of data; give the viewer an easy orientation (atlas colouring, city skylines, etc.); animated data is the only way to show the dynamics of a weather situation; and, finally, depth cueing is essential (shadows of clouds and other objects that are vertically projected onto the map).

7.2 **VISUAL**

7.2.1 *Application fields of VISUAL*

There are two distinct application fields for a scientific, meteorological visualisation software. In research, a flexible tool is necessary that allows to easily configurate according to the respective task. Different models, resolutions, domains, and attributes have to be considered automatically or, at least, with little effort for preprocessing. During runtime, the software has to flexibly support the data management. It should offer, for example, dynamical data loading during runtime or the possibility to comfortably create new colour-tables. In an operational environment, on the other hand, fixed configurations are highly desirable. Changing user interfaces with different sets of parameters confuse the forecaster. The configuration has to be tailored to the specific task. If a meteorologist has to do a VFR flight forecast, he/she wants to see a cross section depicting icing, turbulence, and clouds. If he/she has to deal with synoptic diagnostics, it is necessary to be able to display PV or temperature advection immediately. The acceptance of a 3D system strongly depends on its ability to work in a 2D mode also. Figure 17 shows Europe rendered with parallel projection, depicting the surface pressure and the current weather situation.

7.2.2 *First evaluation of the VISUAL prototype*

In autumn 1997, we implemented the VISUAL prototype at the central forecasting office in Offenbach. There is a whole set of advantages to 3D visualisation in meteorology that encourages us to promote the usage of VISUAL at the DWD. VISUAL is considered as a powerful 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. Forecasters tend to prefer 2D applications like MAP when looking at synoptic scale processes. However, it is considered very useful for local scale problems. Investigating the influence of the topography is one domain of 3D software, but this implies the correct treatment of the model's geometry. We do our best to avoid interpolation, 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 VISUALS's strong features. Therefore, we have implemented a sophisticated contouring package and offer both hardware colour shading and the possibility to do solid contours with splines. Cutting planes can be dumped in various pixel formats, Postscript, or CGM. Context information is also an attribute of the displayed cutting plane or model surface. Thus, the user interaction moves the context information together with the visualised parameter and ensures that the user's orientation is not lost.

During the operational test of VISUAL, we are encountering some problems with the usage of a 3D system in an operational environment. It is difficult to train forecasters who are working on shifts. Although we are offering daily support, they tend to find the user interface too complicated. This should result in the reduction of the complexity of the GUI in the next release. Up to now, we have not yet developed a meteorological concept, how VISUAL could be used to support the generation of meteorological products like weather maps for example. It is still a diagnostic tool to study NWP forecasts or to compare them with observations.

The performance of the whole system is crucial for the acceptance by the user. It is indispensable to run VISUAL on workstations with hardware Z-buffer, a good polyline/polygon performance, and enough memory. We have currently implemented VISUAL on Silicon Graphics Indigo2 workstations with Solid or Maximum Impact graphics and at least 128 MB memory. In order to use some of VISUAL's visualisation capabilities on any MAP workstation without upgrading MAP's hardware (mostly INDYs without Z-buffer), we are implementing a server version that allows to create pre-defined graphical objects like model surfaces and cutting planes in batch mode. They will be dumped as binary objects in DWD's AGS graphics library format or CGM files and sent to the MAP file servers at our regional offices. This concept will be extended by the possibility to interactively request cutting planes through RPC calls.

8. 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. We will develop VISUAL into an application that allows to effectively support the forecaster during his daily work.

We have demonstrated with the TriVis system, that 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.

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