Multidimensional Data Visualisation in Meteorology

GILBERTO CÂMARA[1], LÚBIA VINHAS[1], FERNANDO AUGUSTO MITSUO II[1], LAERCIO NAMIKAWA[1]

BAUDOUIN RAOULT[2], GEIR AUSTAD[2], JENS DAABECK[2]

[1]Image Processing Division - DPI, National Institute for Space Research- INPE

P.O.Box 515, 12201-010 São José dos Campos, SP, Brasil

{gilberto, lubia, fi, laercio}@dpi.inpe.br

[2]Operations Department, European Centre for Medium-Range Weather Forecasts

Shinfield Park, Reading RG2 9AX, England

{baudouin.raoult, geir.austad, jens.daabeck}@ecmwf.int

Abstract. This work discusses the concept of multidimensional data visualisation and its application to the design and development of meteorological visualisation systems. The ideas presented in the paper have been used as a basis for a new visualisation module for the METVIEW system, developed by ECMWF and INPE.

Keywords: Scientific visualisation, Meteorological Application of Computer Graphics, User Interfaces.

1 Introduction

This paper discusses the concept of *multidimensional data visualisation* and discusses its practical application to the presentation of meteorological numerical weather prediction data, in the context of the development of the METVIEW system.

2 Visualisation of Meteorological Data

Meteorological data presents a substantial challenge for scientific visualisation applications, because of the very nature of the data itself. A numerical weather prediction model is based on integration over time of a number of meteorological variables on a three-dimensional grid, which represents the atmosphere.

After the integration is concluded, the post-processing step produces a significant number of derived variables, which are used both for forecasters and for operational analysis of prediction quality.

Additionally, the current generation of NWP centres rely on ensemble prediction systems, which generate a large number (typically 50) of additional predictions, usually at lower resolution than the main model, which are serve as a guidance and estimation of quality and predictability of the main forecast (the "deterministic" one).

Taking all variables into consideration, it can be estimated that a NWP model has 10^{30} degrees of freedom. Presenting such a daunting variety into a two-dimensional screen is clearly no easy task.

The traditional way of visualisation of meteorological NWP model is two-dimensional contours and shaded maps, whose semantics are clearly understood by the user community, and who present the advantage of being easily printable. In fact, traditional 2D colour presentations still are the predominant way of sharing visual information in the meteorological community.

The use of three-dimensional visualisation and animation for Meteorology was only accepted by the user community when such systems provided interfaces which simulated the dynamic behaviour of the atmosphere, and provide a rapid and interactive response (Hibbard et al, 1994). Even in this case, the limitations of human perception do not allow, in practice, more than three variables to be displayed at once. Therefore, in such systems, the user usually chooses one or two variables and follows their behaviour over time and space.

One additional feature of meteorological graphics in the great variety of possible presentations associated with the same data set. Consider, for example, a 4D distribution (space and time) of one meteorological variable (e.g., temperature) as produced by a NWP model. Such distribution will consist of as many fields as there are vertical levels in such a model for representing the atmosphere (in ECMWF's case, 31 levels), multiplied by the time-steps produced during the integration (in ECMWF's case, four time instances are stored per day). Therefore, in the case of a 10-day forecast, there are many different ways of presenting this data set, including:

- A 2D sequence of contour maps presented in the screen or printed.
- A 3D visualisation, with animation, usually of selected isosurface of the interpolated values.
- A "cross-section" of a set of vertical fields, showing a 2D vertical slice of the atmosphere.
- A "vertical profile" of one time-instance of a set of vertical fields. In this case, the different values associated with one single point in the earth's surface are shown in a graph, where the horizontal axis shows the variation of the variable, and the vertical axis is associated with the different vertical levels of the atmosphere.
- A "meteogram", which shows the time evolution of one single location, on a fixed vertical level. In this case, the horizontal axis is associated with time and the vertical axis indicates the variation of the variable.

These different types of graphical presentations are widely used in the meteorological area. Ideally, users would like to combine these types of presentations, a feature, which is not easily available in the current generation of meteorological visualisation systems. These limitations were the motivation for the theoretical and practical work, presented in the next sections.

3 Multidimensional Data Visualisation

In the context of this work, the concept of multidimensional data visualisation can be described as *the presentation of different and coherent perspectives of the same data set.* The idea of different perspectives (or *views*) of the same data set stems form the discussion outlined in the previous section. The notion of "coherence" states the fact that these views are linked, that is, changing the data set should affect all presentations simultaneously.

The basic problem addressed by multidimensional data visualisation is the development of techniques for projecting data from higher dimensional space to the lower dimensional space of our graphics presentation hardware (Kiem and Kriegel, 1996).

The idea of multidimensional data visualisation is presented in Figure 1, where the same data set (in this case, a set of 10 vertical fields of a meteorological variable), are shown in three different views. In the top left picture, a "vertical profile" is presented. The top right picture shows a "cross section" of the same data set.

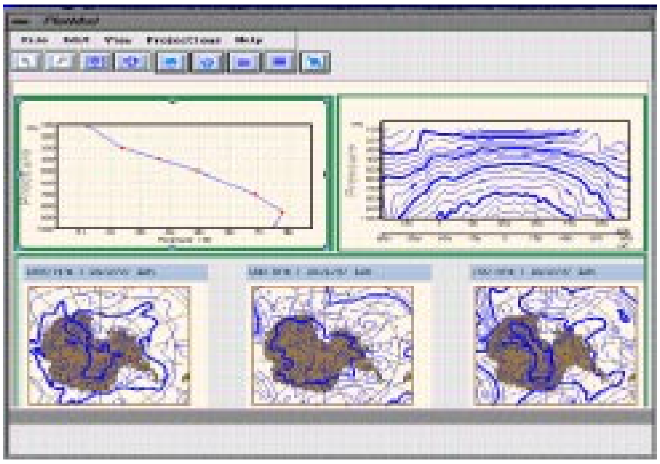

Figure 1 – Multidimensional Visualisation Concept.

4 Practical Application in METVIEW

4.1 General Description

The concept of multidimensional visualisation has been applied in practice as the conceptual basis for a new visualisation module for METVIEW, a system for retrieval, manipulation and visualisation of meteorological and climatological data (Daabeck et al, 1997). METVIEW is a joint development of the of the European Centre for Medium-Range Weather Forecasts (ECMWF) and Brazil's Centre for Weather Prediction and Climate Studies (CPTEC), with participation from the French Weather Service (Météo-France).

METVIEW is based on distributed software architecture (Raoult et al., 1995), where different co-operating modules combine to provide a flexible and powerful application. The system is being used at many weather prediction centres in different countries, including ECMWF, Brazil, France, Denmark, Sweden, Greece, Italy, Spain and Portugal.

4.2 Choosing Appropriate Interface Metaphors

One very important problem, which arises in connection with multidimensional visualisation, is the appropriate choice of user interface metaphor, which would allow the definition of the different drawing areas and to allow easy selection of the data to be visualised. In METVIEW, a *tree* metaphor, coupled with a *direct manipulation* mechanism, provides appropriate support for both needs.

The tree metaphor is depicted in Figure 2, and uses the following concepts:

- *Superpages:* corresponds to an independent drawing area (screen or canvas), where the user wants to display multiple presentations of the same data set.
- *Pages*: parts of the drawing area, where data is shown (Figure 1 has three pages, two in the top part and one in the bottom).
- *Subpages*: data-dependent drawing areas, which are places where a page places its graphical output (in Figure 1, each of the top pages has one subpage, and the bottom area has 10 subpages, out of which 3 are currently visible). Whilst the actual number of subpages is data-dependent, not all subpages of a given page are displayed simultaneously. A scrolling bar allows the user to display all subpages.
- *Views*: each page is associated to one view, which defines how the graphical output is produced.

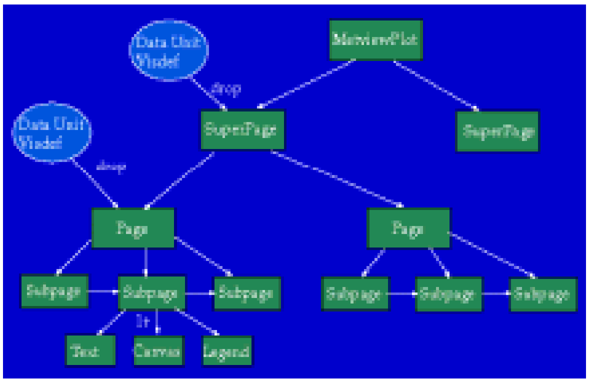

Figure 2 – Tree Hierarchy for User Interface.

In Figure 1, there are three views: the upper right page is mapped to “cross section application, the upper left page, to a vertical profile, and the lower page to a 2D geographical area.

The combination of this page hierarchy with direct manipulation allows the user to drag data from an icon-based interface, such as the one used by METVIEW, and to drop it onto a superpage or onto a page. In the former case, data dropped at nodes will be applied recursively down the tree, until they reach the lowermost level. In other words, data dropped at this level will be visualised in all pages (which will have different views).

This recursive descent allows the user to view the same data in different ways. For example, the same set of fields could be seen as a set of contours, cross sections, vertical profiles or time axis, as in Figure 1.

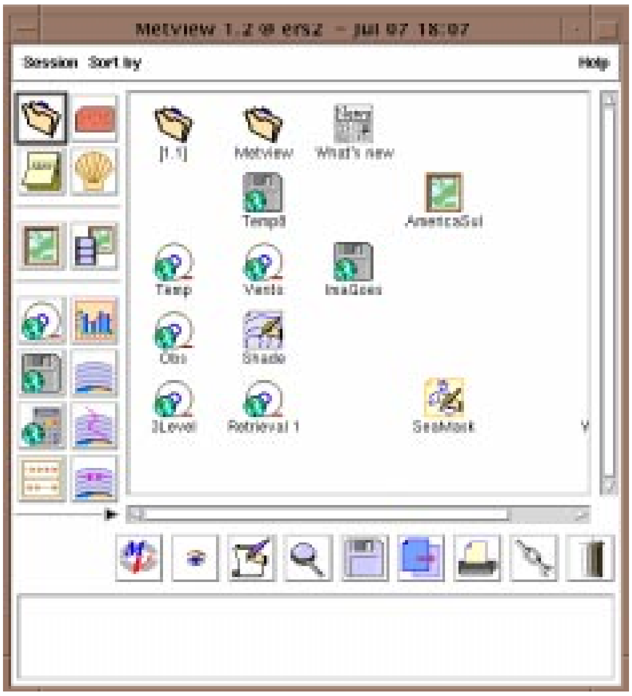

Figure 3 – Icon-driven interface for METVIEW

4.3 Implementation and User Acceptance

The ideas outlined in this paper have been implemented in the new visualisation module of METVIEW by the authors. Implementation started in mid-1997 and, in the beginning of 1998, an initial version of this module has been made available internally to ECMWF users. After a trial and evaluation period, this module will be made available, as part of the forthcoming general METVIEW releases.

5 Conclusion

Meteorological data presents a significant challenge to visualisation applications, because of the enormous inherent dimensionality. The use of multidimensional data visualisation techniques, as described in this paper, is a promising way of addressing the problem of display a very complex data set using 2D/3D graphics techniques.

The concepts presented in this paper are applicable to other scientific disciplines whose semantics exceed the traditional 2D/3D visualisation techniques, such as Remote Sensing, Geographical Information Systems and Computational Chemistry.

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