Advanced Flow Representations Applied to Wind Visualization

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Abstract

In the first part of this paper, we briefly describe the NWP operational suite of MétéoSuisse, where and how it is installed and which are its main components. The emphasis is not put on the technicalities but on the way MétéoSuisse operates its NWP activities. At the difference of the majority of the National Weather Services, MétéoSuisse runs its operational suite and conducts its development works not independently, but in joint venture with the Swiss Center for Scientific Computing (SCSC). This partnership has brought to both organizations much more synergies and output than anticipated and an enhanced visibility in meteorological and climate research.

In the second part of the paper, the latest developments performed at the SCSC in the field of model data visualization are presented. They focus on truly new representations of model wind fields. These developments will be incorporated in the operational model forecast production.

1. Introduction

In the frame of their collaboration in the field of High Performance Computing and Networking (HPCN) for Numerical Weather Prediction (NWP), MétéoSuisse and the Swiss Center for Scientific Computing pursue both operational NWP integrations and R&D activities in the frame of international weather and climate research programs like the Mesoscale Alpine Program [4]), the EUMETNET Short-Range NWP Program, the EUCOS Program as well as contributors to national programs, in the first place with the National Competence Center for Research (NCCR) of the Swiss Science Foundation.

In this paper we present the MétéoSuisse operational suite at CSCS, the HPCN capability and capacity used for both the operational NWP production and the R&D activities. The key support lines and the joint development areas in the field of HPCN including competencies in data handling, overall performance monitoring, optimisation (from wide-area-networks to application-SW-engineering) and visualization are also briefly presented.

In particular we present this year a contribution made at CSCS for improving model wind representations. Arrow plots are still widely used in the meteorological community to depict wind information. However, it is well known that they lead to interpretation difficulty when looking at these wind fields due to their discrete nature and occlusion problems. For few years, researchers in the flow visualization field have proposed alternative representations for depicting vector fields. We present these advanced representations as well as our integration effort into Vis5D+, the open-source meteorological visualization software.

2. MétéoSuisse Operational Suite at CSCS

The operational suite of MétéoSuisse has been migrated to CSCS during the year 2000. It consists in a software package developed at MétéoSuisse and installed on an Origin3200. Data acquisition, simulation control, product generation and dissemination are all carried out on this 4 CPUs machine. The integration of the model is performed on a NEC SX-5 parallel vector supercomputer which has recently been upgraded to sixteen processors giving an aggregated peak performance of 128 Gflop/s and featuring 64 Gbytes of shared memory.

Twice a day the model is integrated with the lateral boundary conditions produced by the DWD global model called GME. The initial conditions come from our continuous data assimilation procedure based on the nudging method.

2.1. *The NWP model*

In the frame of the COnsortium for Small-scale MOdelling (COSMO), the National Weather Services of Italy, Greece and Switzerland, under the lead of the National Weather Service of Germany, have developed a new non-hydrostatic meso-scale model called the Local Model. This model is based on the primitive hydro-thermodynamical equations describing non-hydrostatic flow for a moist atmosphere, without any scale approximations. The model equations are solved numerically using finite differences on an Arakawa C-grid with a generalized terrain-following vertical coordinate. The numerical scheme used is a slit-up method separating the fast wave generating terms from the other terms (advection and adjustment) of the equations. For both part, the explicit centred time scheme is used. A thorough description of the Local Model itself can be found on the COSMO web site (http://www.cosmo-model.org).

The version of the Local Model running at MétéoSuisse, named aLMo (for aLpine Model), is integrated on a 385x325 grid-point mesh, with a $\frac{1}{16}°$ mesh size (about 7km), for a domain covering most of Western Europe. In the vertical, a 45-layer configuration is used; the vertical resolution in the lowest 2 km of the model atmosphere is about 100m.

As already mentioned, the data assimilation is based on the nudging or Newtonian relaxation method. This technique has been implemented using local relaxation of the model prognostic fields towards direct observations. The observations being assimilated are horizontal wind, temperature and relative humidity at all levels, and pressure at the surface model level. Currently only data from conventional observing systems are used: surface observations (SYNOP, SHIP, DRIBU), aircraft observations (AIREP, AMDAR) and vertical soundings (TEMP, PILOT). An overview of the operational suite can be found on Figure 1.

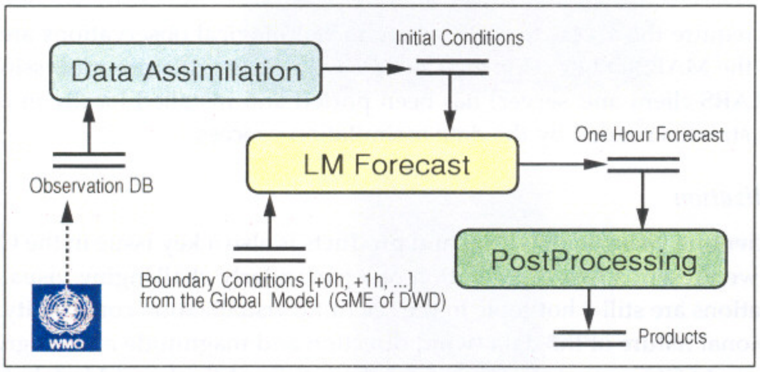

Fig. 1: Process diagram of the operational suite

2.2. *The CSCS Support Model*

The Swiss Center for Scientific Computing (CSCS) is part of the Federal Institute of Technology in Zurich (ETH Zurich). It has two missions: to provide the Swiss scientific and computational community with advanced computing and networking facilities (Fig. 2), and to build a strong research group in computational sciences.

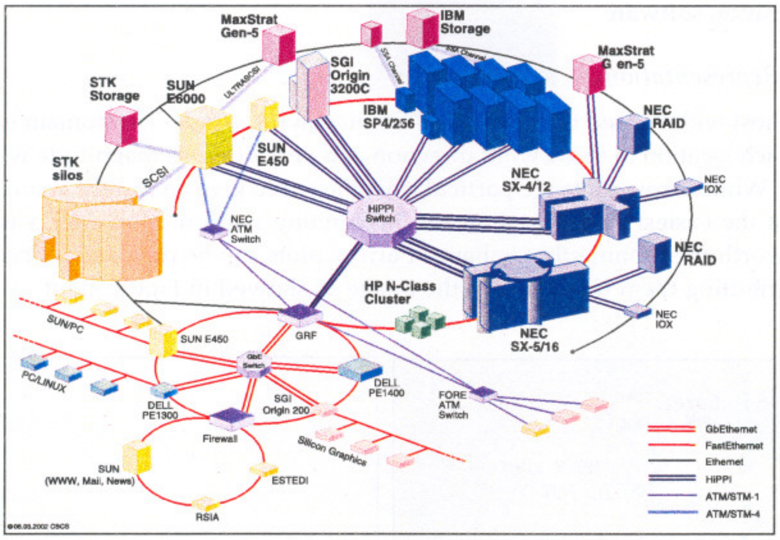

Fig. 2: CSCS HPCN Environment

CSCS guarantees leading professional, technical and scientific competency transfer to its prominent community of end-users, and ensures them the computer resources they need to stay at the forefront of their discipline in computational science. The provided support has to be seen as a natural complement to the activities and research of the customers. Thanks to the joint efforts of scientists and computer specialists, the added value to research is very effective. This kind of customer support lets scientists fully focus on their scientific problems, while computing specialists take care of technical aspects, making sure that the best solutions and results are obtained. Significant efforts are invested in the optimisation of user codes.

In the frame of the MétéoSuisse operational suite, at least three main axes of collaboration and support have been actively pursued.

2.2.1. *LM Code Optimisation*

Production runs are subjected to an elapsed time window of 90 minutes; code optimisation helps increasing the size the of the computational domain and/or the amount of forecasted hours that can be obtained under such a constraint for a given horizontal and vertical resolution. The current optimised version [2.14] of the model achieves a sustained performance exceeding 24 Gflop/s on 12 NEC SX-5 CPU's, resulting in a 60% performance gain with respect to the original version.

2.2.2. *MARS DB*

Data assimilation runs require the access to a DB where meteorological observations are stored in real-time. For this purpose, a copy of the MARS DB developed at ECMWF (including the pre-processing and decoding/quality control software, the MARS client and server) has been ported and installed locally in order to store the above-mentioned observation streams needed by the data assimilation process.

2.2.3. *Scientific Visualization*

Development of new scientific visualization tools and products is also a key issue in the CSCS support concept for its users. In this paper we present a first contribution of a particularly challenging visualization of the wind evolution. These representations are still a hot topic in the scientific visualization community. The difficulty is mainly due to the high dimensional nature of the data (wind direction and magnitude at each grid point, both varying in time). We are developing at CSCS a post-processing for the results of the Local Model of MétéoSuisse. This post-processing is based on flow texture approaches and the animations produced will eventually be part of the visualization package that Swiss forecasters receive twice a day.

3. Recent Advances in Wind Visualization

Few years ago, flow visualization researchers have proposed alternative representations to the traditional arrow plots depicting vector fields. However, those techniques are not yet widely used to visualize wind information in meteorological representations. The following sections give an overview about current wind representations (section 3.1), present new potential visualization methods (section 3.2) and expose an extension project for Vis5D+ meteorological visualization software.

3.1. *Current Wind Representations*

Arrow plot is still the most widely used representation for displaying winds. The domain is regularly sampled and an arrow is drawn at each location to show wind direction and very often its magnitude with proportional lengths or via the use of bards. While arrow plots are particularly efficient to give an insight about local wind information (Figure 3 left), it is not the easiest representation for interpreting wind motion over a whole domain (Figure 3 right). However, it is worth mentioning that enhanced arrow plots can be obtained by bending the arrows along the local flow and distributing them uniformly in the image as showed in Figure 4 left.

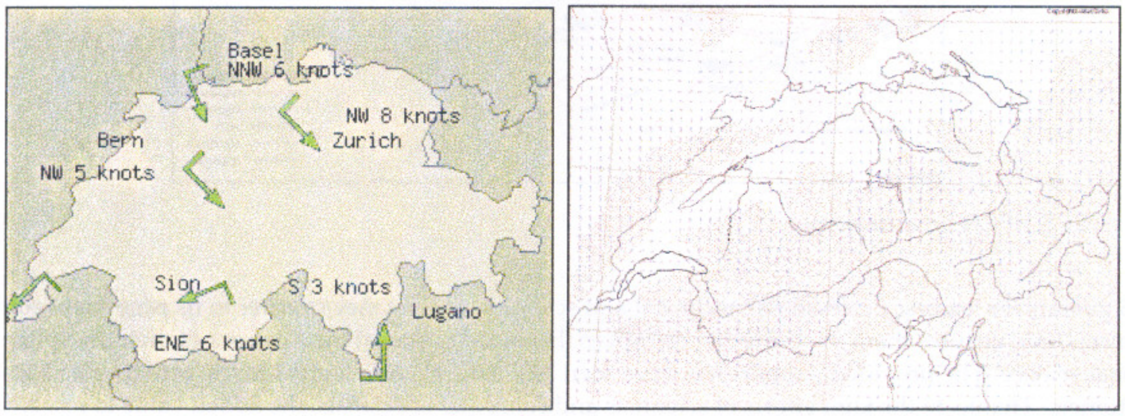

Fig. 3: Arrow plots provide clear local information (left) but are not suited to reveal structure complexity over a whole region (right).

Although rarely used, streamline representations are more suited to display wind structure. A set of streamlines - curves everywhere tangent to the vector field - indicates instantaneous wind direction in a more continuous form. Mental interpolation between consecutive arrows is not needed anymore. We developed some years ago an algorithm that evenly places streamlines to improve wind interpretation by avoiding artefacts due to too high or too low density of curves [7]. Figure 4 right shows a typical representation obtains with such an algorithm. However, due to their instantaneous nature, streamlines are not suited to depicting temporal dimension of winds.

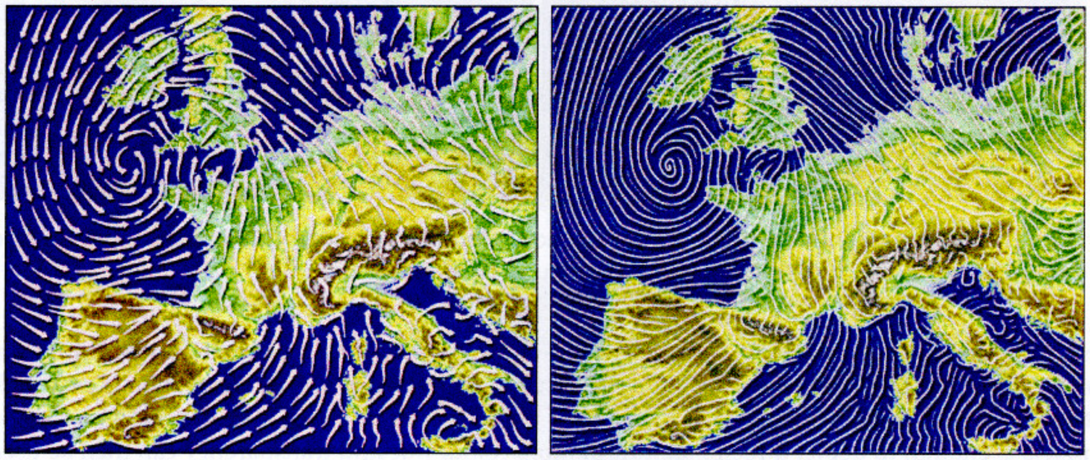

Fig. 4: Enhanced "traditional" wind visualization with evenly-spaced arrows (left) and streamlines (right)

An important aspect as far as meteorological information is concerned is its temporal dimension. Both observations and predictions are time functions, but the time evolution of the meteorological variables is rarely visualized. Although animated loops of cloud cover or precipitations are widely provided, wind evolution remains a difficult function to visualize. A simple method consists in animating arrows "attached" to a regular grid covering the domain. The arrows move as tangents to the wind, as would do hundreds of flags. Motion is visible but interpretation of the wind evolution remains nearly impossible. Arrows are certainly not the appropriate tool.

In the following section, we describe recent advances in flow visualization. We show their benefits for static and animated representations.

3.2. Wind Visualization with Flow Textures

In the last ten years, new types of flow representation have appeared, based on texture generation. Instead of placing sparse geometric objects such as arrows or curves, texture-based techniques use pixel correlation to carry information about flow direction, orientation and velocity magnitude. They are the best way to achieve the densest representations. In this paper we talk about flow textures for referencing these texture-based representations.

Historically, the first texture-based technique for visualizing flows was presented by van Wijk in 1991 [10]. It was called SpotNoise and consisted in blending many elliptical spots whose shape was stretched to reflect the local flow direction. In 1993, *Cabral et al.* proposed a new approach called Line Integral Convolution (LIC) [5]. The convolution of a white noise image along 1-D kernels composed by a dense set of streamlines brings spatial correlation between pixels and clearly reveals flow direction. This technique has been improved along the years to speed up its computation [9] and to reveal flow orientation by means of asymmetric convolution kernels [11] or animation [6][9]. During a few years, flow texture representation was only possible for steady vector fields and attempts to apply it to unsteady flows failed to achieve sufficient spatio-temporal correlation or good image quality.

Recently we developed innovative algorithms based on the texture advection technique that achieves good quality for the animation of unsteady flows [8]. The principle is to warp the flow with a noise texture and to blend successive textures to introduce spatial correlations. Technically, pixel colour of a texture is deduced from the previous time step texture. The algorithm operates in two phases. Firstly, pixel positions from where to copy the colour in the previous time step texture are determined by computing the position of each pixel backward in the flow. Secondly, pixel colour in the new texture is copied from the originating pixel in the previous texture. A special care has to be taken in region of incoming flow, that is, where the backward integrated position references a location outside the texture domain. In this case, random noise values are injected seamlessly in those regions. A temporal filter is applied to successive frames to reveal grey streaks parallel to the flow. Due to the efficiency of the algorithm, texture generation is achieved at several frames per second.

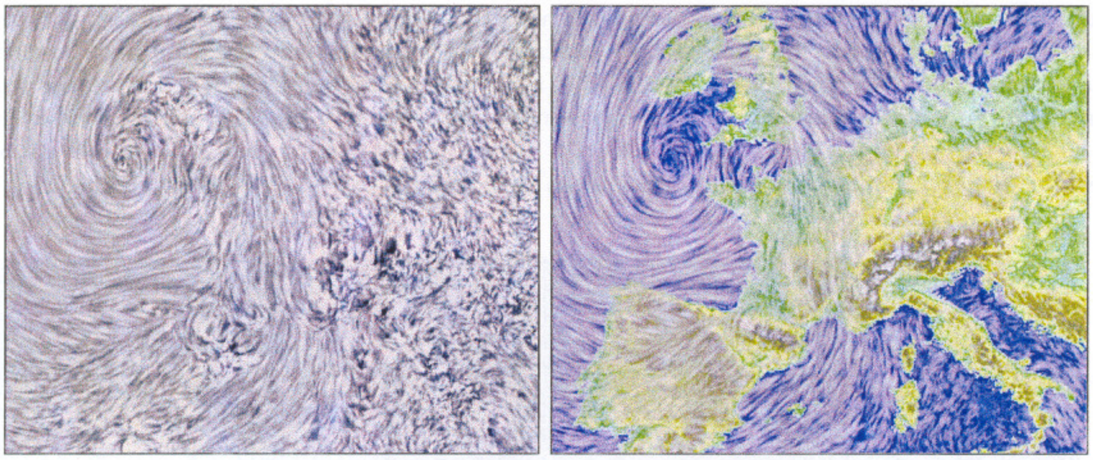

Fig. 5: Flow texture representation. Left: wind direction encoded in a greyscale image. Right: topology information is carried by colours and wind magnitude by transparency.

Applied to meteorology, flow textures are a powerful tool to depict wind information. Wind direction is available over the whole domain independently from the vector field resolution. Its interpretation is easy and its dense and continuous aspect avoids mental interpolation to follow the flow. Since intensity variation among neighbouring pixels is enough to depict directional information, colour hue and transparency can then be used to show velocity magnitude and other scalar quantities (see Figure 5). We can take advantage of this to depict how winds advect other quantities such as temperature or humidity.

In the next section we present the ongoing project at CSCS concerning the integration of our flow texture representations within the Vis5D visualization software.

3.3. Vis5D+ Extension

Vis5D is a software package that is widely used by scientists to visualize the output of numerical simulations of the Earth's atmosphere and oceans. Bill Hibbard, a member of the Alliance Environmental Hydrology Application Technologies team, Johan Kellum, and Brian Paul developed it. The three were colleagues at the University of Wisconsin's Space Science and Engineering Center (SSEC) when the software was first created.

Vis5D offers isosurfaces, contour line slices, coloured slices and volume rendering of scalar data defined on a 3D grid. The resulting 3D scene can be rotated and zoomed in real time. The scene can be animated in order to see time evolution of the data. Vector data are also visualized on horizontal or vertical slices as arrow plots or sets of streamlines (see Figures 6a and 6b). The visualization capabilities for meteorological data of Vis5D has been integrated into Metview, the ECMWF visualization system.

Fig. 6: Available vector data representation in Vis5D. (left) arrow plot and (right) streamlines

Vis5D development has ceased at SSEC and Vis5D+ is now the recommended version. Vis5D+, initiated by Steven Johnson (MIT) is the open source successor of Vis5D. It is intended as a central repository for enhanced versions and development work on Vis5D. Therefore, we naturally chose to extend this version with our new representations.

Our extension will consist in adding two new widgets on the graphical interface that allow displaying vector information onto slices or mapped on the orography. As already available in Vis5D with isosurfaces, it will be possible to merge supplementary colour information issued from any other scalar data with vector information (winds and temperature for instance). The integration of our algorithm is in progress and Figure 7 shows preliminary results. We planned to release a first version in spring 2002.

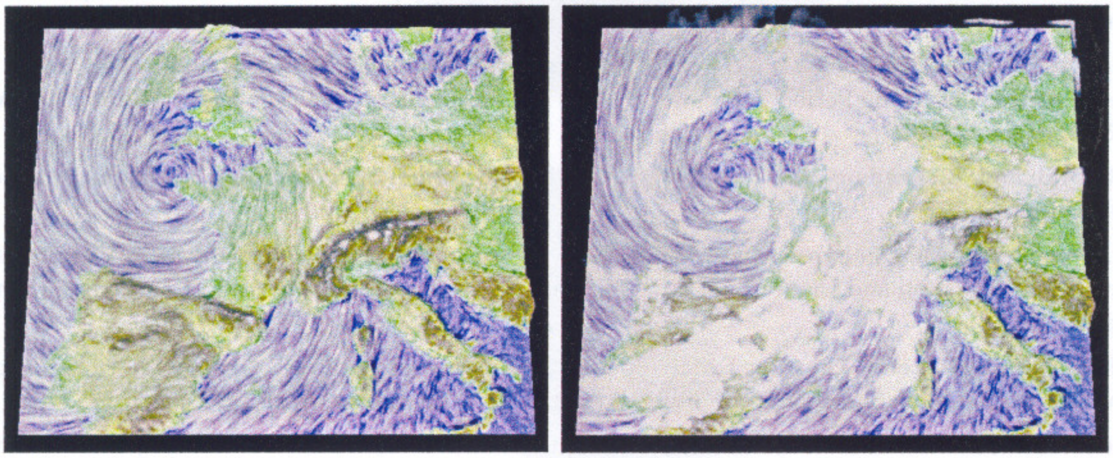

Fig. 7: Vis5D vector data visualization extended with flow texture representations (left). Winds and clouds visualization within Vis5D (right)

4. Conclusion

We presented some new developments in the field of HPCN for NWP and in the frame of the-CSCS collaboration. In particular we have presented some new flow representations based on flow textures that might further improve the MétéoSuisse NWP products. We showed that their dense nature is particularly well adapted to represent wind fields and that they allow to embed naturally the time evolution of the winds. We presented as well the efforts we have been investing at CSCS to integrate these new representations into Vis5D+ open-source meteorological visualization software. This effort should benefit the whole meteorological community using Vis5D+ directly or via the ECMWF visualization software Metview.

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