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Short Papers

3D visualization of atmospheric data for analytical approaches

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Abstract

In the future, climate change will strongly influence our environment and living conditions. Climate simulations that evaluate these changes produce huge data sets. The combination of various variables of the model with spatial data from different sources helps to identify correlations and to study key processes. We visualized results of the WRF model for two regions. For this purpose, we selected visualization methods based on specific research questions and combined these variables in a visual way. These visualizations can be displayed on a PC or in a virtual reality environment and are the basis for scientific communication for evaluating models and discussing the data of the research results.

Categories and Subject Descriptors (according to ACM CCS): I.3.8 [Computer Graphics]: Applications—

1. Introduction

Exploring the processes and correlations of our climate and the weather is an important issue in times where it is conceivable that our environment and living conditions will change rapidly in coming decades because of the changes to our climate system. In Europe, for example, the biggest changes can be found in the fragile alpine ecosystem where the large temperature increases have led to the melting of glaciers [EG07]. To evaluate these changes, climate models that include basic and process conditions are developed and simulations have been run. Especially regional climate simulations are interesting because they show the regional effects of the changes in weather statistics for humans and the environment. The weather research and forecasting model (WRF, [MDG04]) is such a mesoscale numerical model. The WRF model can be operated with very high resolution so that, for example, the specific climate conditions of high mountains can be studied.

For improved insight into these complex spatial data sets, 3D visualization is an appropriate instrument. For example, correlations between variables like wind vectors, humidity and cloud coverage can be made visible. Furthermore, inconstancies in the data and errors in measurements caused by incorrect calibration can be easily detected [RFSK12] [JS03]. With the help of visualization, different spatial data sets from different projects and sources can be combined. Thus, correlations or inconsistencies between various data sets can be visualized. For example, the data from climate models can be compared with measured data to find out whether the models are accurate [HRM*12].

The challenge of data integration is to deal with very heterogeneous data sets that differ in their resolution, spatial and temporal dimensions, structure, such as vector data, measured and simulated data, and remote sensing data. These different data sets make some preprocessing methods necessary [RFSK12].

The data sets of climate simulations are very extensive and include a lot of different variables from various compartments, see 3.1. To solve complex research questions, it is necessary to visualize several quantities at the same time. The aim of this paper is to establish visualization set-ups that offer easy-to-understand, well arranged visualizations, for example to show all relevant variables for the energy balance of a study area.

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2. Related work

In the field of visualization of atmospheric data sets there are a lot of existing software tools. Makai Voyager [AA10] and TriVis [HBH00] are two examples of commercial software. An often used free software for atmospheric visualization is the OpenGL-based VIS5D [HAF*96]. Unfortunately, its development – even of the successor software VIS5D+ – stopped in 2002. A software that was specially developed for WRF files is VAPOR [CMNR07]. Besides these software tools, there are many more that are usable for the visualization of atmospheric data, such as IDV [WM08], OpenDX [BFT01] and Weather3DeXplorer [KvdNL*11].

For our visualization, we decided to use the open source software ParaView [AGL05], which is based on the visualization tool-kit [SML06]. ParaView offers a range of visualization filters, add-ons and the options to implement further software functionality. Concerning data integration, ParaView has interfaces for most common import and export formats that are necessary to run the visualization. Finally in contrast to most of the other software packages, ParaView supports a true 3D visualization, which is necessary for studying the climate processes.

Finding appropriate visualization methods for simulated variables like clouds [Tre01] or measured environmental data [JPGB11] can be difficult. It has to be considered about how various variables can be visualized together [FW10]. There is a limit to how many variables can be visualized without producing confusing scenes. To aid understanding of the visualization of these big data sets, immersive virtual reality environments [DF00] [vDLS02] can be used, where users can move through the data. To find the most suitable visualization for a specific case, it is necessary to conduct user studies [KHI03] [Joh04] in the form of expert interviews, for example.

3. Methods and results

To explore the possibilities of the scientific 3D visualization of atmospheric data, we selected two case study areas at different scales that include various landscapes. The first one is the area of Baden-Württemberg, a federal state in the south-west of Germany. The study area extends 300 x 300 km and involves varied landscapes like the north-western Alps, the Black Forest and the Rhine River Valley. This area is one of most active regions in Germany with respect to convective precipitation. Therefore, it was the subject of large modelling and experimental efforts, particularly during the Convective and Orographically Induced Precipitation Study (COPS, [WBK*11]). The second study area is northern central Europe with an expansion of 1300 x 580 km. The landscape involves the south west of Germany with the Alps, the lowlands in the north of France, Belgium and the Netherlands as well as the English Channel and the south of Great Britain. This is a common domain of regional climate simulations for Europe covering a great part of the weather variability such as propagation of frontal systems. To explore different weather events, we chose a typical summer day with a warm, dry climate for the region of Baden-Württemberg and a typical winter day with moist, cold climate and snow for the region of northern central Europe.

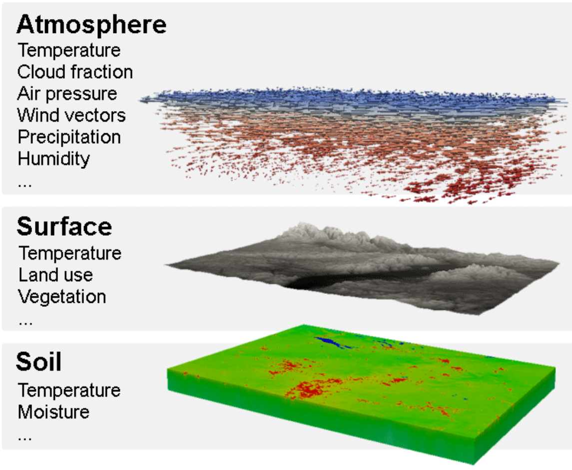

Figure 1: *The visualization is partitioned into three compartments with their specific variables: atmosphere, surface and soil.*

3.1. Data integration

The first step towards to the visualization is data integration. The data source providers can be very different; they include research facilities, regional authorities and in some projects even companies. In our case study, the simulation data is produced by the Institute of Physics and Meteorology of the University of Hohenheim as part of the WESS project [GRW*13]. Other data such as administrative divisions, protected areas and maps for potential renewable energy are from the regional authorities of Baden-Württemberg and institutions that contribute to the European INSPIRE project [Ill09].

The data we use for the visualization is very heterogeneous. It consists of raster data (e.g. measured data, forecasts for renewable energy), multi-dimensional arrays (e.g. simulation data) and vector data (e.g. borders, observation sites). For the visualization of atmospheric models, there are variables from three different compartments: atmosphere, surface and soil (see figure 1). To include all these data into the visualization system, some preprocessing is necessary. For the simulation data that uses the netCDF format [RD90] we used cdo [SK06] and NCL [Uni13] among others to convert it. For the vector data, we used ArcGIS [LC13] along with other GIS tools to transfer it to the used coordinate system. To prepare the data for the visualization with ParaView, we used the OpenGeoSys DataExplorer [KBL*12].

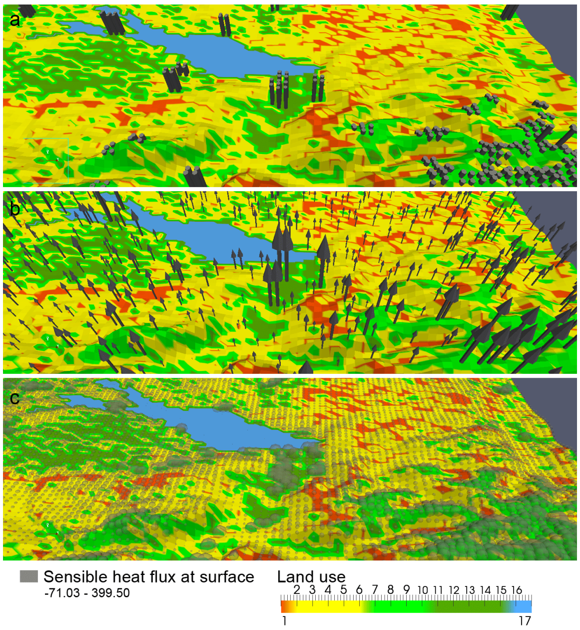

Figure 2: *Comparison of different visualization methods for specific 2D variables, in this case sensible heat flux combined with the DEM and a texture that represents the land use categories. (Displayed area: Lake Constance and west Alps)*

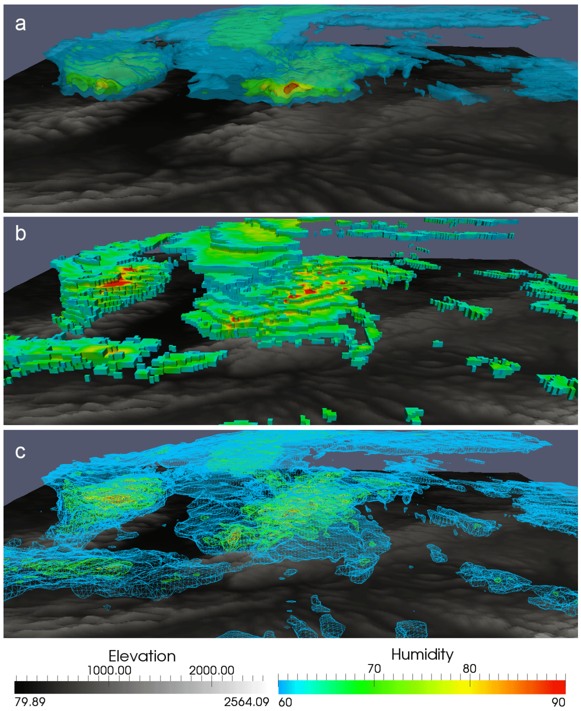

Figure 3: *Comparison of different visualization methods for specific 3D variables, in this case the various percentages of the humidity combined with the DEM. (Displayed area: Baden-Württemberg)*

3.2. Visualization methods

If there is a large amount of heterogeneous data, as in the example described, it is necessary to find appropriate visualization methods for the variables for each specific research question. Choosing the appropriate representation for each variable helps distinguish one variable from another. Attributes like color, brightness, and saturation, opacity, shape and size can be used. Combinations of these can also be appropriate. If the resolution of the data is too high to make every value visible, it can be useful to select only some of the data. This can be done by defining a range for the value, choosing values randomly, reducing values with generalization or down-sampling, or defining buffers for the values. In some cases, even combinations of these selections are suitable.

To find an appropriate visualization method, we compared the methods and evaluated them with experts of meteorology. An example for a 2.5D visualization of a variable, in this case sensible heat flux at the surface combined with the digital elevation model (DEM) and the land use categories used for the texture, is shown in figure 2. For figure 2a, we used a defined range to select values and the height of the bar to indicate the size of the value. In figure 2b, the values are randomly selected and the size of the value is represented by the scaling of the arrows. Figure 2c shows all values and uses opacity to avoid obscuring the texture information. The size of the value is represented by the scaling of the spheres.

Another example is displayed in figure 3 and shows the 3D visualization of the humidity combined with the DEM. In all pictures the different humidity percentage is represented by a defined color. For figure 3a, we used semitransparent iso volumes and sliced them to gain insight. Thus, the percentages of humidity are clearly visible, but we can only display some of the values. Figure 3b shows the humidity values without interpolation. Here it strongly depends on the occurrence of the different values if they are visible at the surface or if there is occlusion. In figure 3c, we used wire-frames to represent the iso volumes of the humidity. The advantage of this representation is the clear visibility of the various percentages and that all the values of the data set are visible simultaneously.

3.3. Data combination

After discussing the different visualization methods, the next step is to select the variables that are relevant for the defined research question. To evaluate the visualizations, we conducted user tests, in our case in form of expert interviews to analyse and discuss the visualizations.

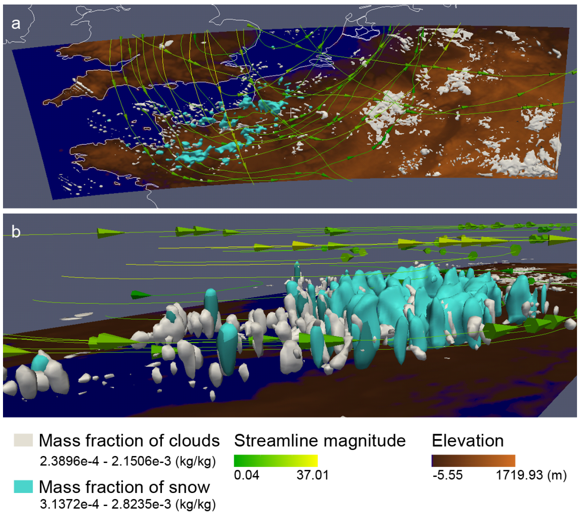

Figure 4: *An example of the visualization of wind vectors combined with the iso volumes of the mass fraction of clouds and snow. (Displayed area: Northern central Europe)*

One research question that we focused on deals with the cloud coverage connected to the wind fields in the case study area in northern central Europe. Figure 4a shows a scene from above. For a better orientation, the borders of the continent were added. In figure 4b, the 3D expansion of the mass fraction of clouds and snow is displayed in combination with wind vectors. These displays can be used to estimate the mass transport in and out of clouds, which is essential for process studies and model verification.

Other use cases deal with the energy balance, where mainly the variables of the sensible, latent and ground heat flux play a role. Variables like temperature and albedo as well as the humidity influence the system of the energy balance. Figure 5 shows a scene with a combination of the sensible heat flux, displayed as semi-transparent spheres, with the albedo values, displayed as arrows, and the humidity, displayed as semi-transparent iso volumes. The basis of this scene is the DEM with a texture that shows the land use classes. This visualization helps to study the energy balance closure in dependence of soil and vegetation parameters, which is currently a subject of extensive research.

4. Conclusion and Outlook

One major goal of this kind of 3D visualization is to give better insight into complex heterogeneous data sets and the correlations between the included variables. The visualization is used in the field of scientific communication and for presentations for stakeholders or scientists of other domains. We described the visualization of atmospheric model results exemplarily for two regions, Baden-Württemberg and northern central Europe. The visualization system we chose is

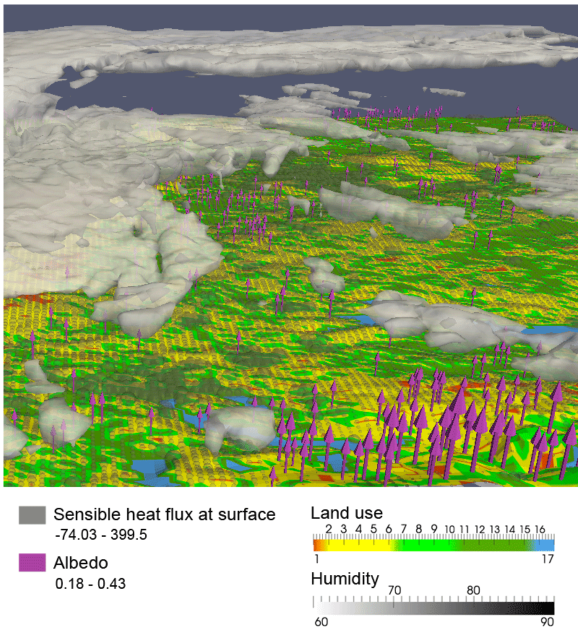

Figure 5: *This visualization shows variables that are part of or effect the energy balance system: The sensible heat flux at the surface is combined with the albedo and the humidity on the DEM with a texture that represents the land use categories. (Displayed area: South of Baden-Württemberg)*

ParaView. We compared different visualization methods of various variables and evaluated their suitability for defined research questions. The visualizations that were evaluated with the help of expert interviews can be displayed on PCs or in a virtual reality environment.

Further development is focused on the challenges of big data sets for software and preprocessing. Furthermore, a user test is planned where non-experts evaluate additional benefits of the 3D visualization in an virtual reality environment compared with a 2D visualization.

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