Workshop on Visualisation in Environmental Sciences (EnvirVis) (2013), pp. 1–5
O. Kolditz, K. Rink and G. Scheuermann (Editors)

Visualization of Urban Micro-Climate Simulations

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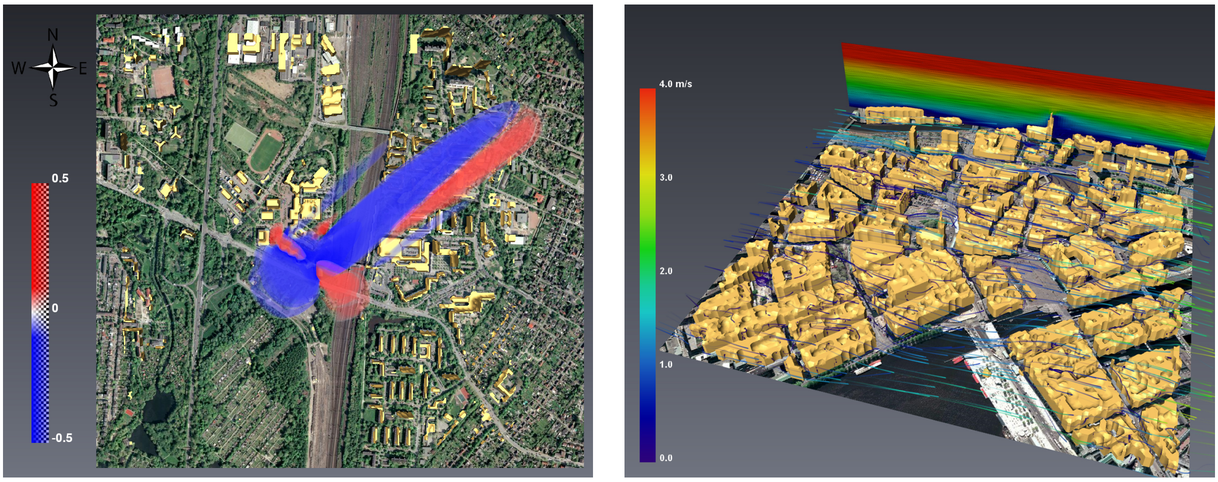

Figure 1: a) Wind Velocity Changes due to Construction. b) Air Flow through the inner City of Hamburg.

Abstract

Climate simulations range from projections with global coupled models of the earth system down to simulations of small scale phenomena, and can cover time scales between seconds up to thousands of years. This work focusses on urban climate simulations and discusses best practices for the visualization and analysis of such data sets. For this task, only state-of-the-art visualization techniques are used, which are available in most visualization packages. The goals for these visualizations are investigative, as well as for communication and presentation purposes.

Categories and Subject Descriptors (according to ACM CCS): J.2 [Computer Applications]: Earth and Atmospheric Sciences—

1. Introduction

Current climate simulations project an increase in global mean temperature by several degrees Celsius towards the end of the century [SQM*07]. This increase, however, will not be homogeneously distributed over the earth surface, instead, some areas will heat up more quickly and dramatically than others. This is especially true for the polar regions, as well as for larger cities. Cities and large urban structures will heat up more quickly because of the materials employed for construction. Cities are, viewed from an abstract perspective, a conglomerate of hard materials, e.g. rocks, concrete and asphalt, which absorb and store heat energy very effectively, thus heating up efficiently. In order to facilitate a good living environment, cities and urban planners have to adapt to these climatic changes, and have to develop strategies to cope with extreme weather conditions, and a possibly overall hotter and drier climate. Architecture, and a carefully crafted urban environment, i.e. more open water areas and trees, can reduce some of these problems, but small scale climate simulations that are able to model such processes are required to understand these fragile mechanisms in detail [Sch03] [TKct]. MITRAS is a micro-scale climate model that is able to model such small scale processes.

2. Related Work

An overview on various visualization techniques and systems used by the climate research community is given in [NSBW08] and [?]. Most of the tools discussed focus on the visual analysis of simulation data on global and regional scales. A world map, texture and orography, is used to add a geographic context. This context is even more important on urban and micro-scale levels. For the analysis of climate development in urban areas, interactions between buildings and the atmospheric boundary layer are modelled in wind tunnel experiments and by using numerical simulations. Here, primarily only 2D visualization methods are used by the domain scientists (see e.g. [Sch03]) – compare also with 2 – even though the boundary layer flow around obstacles within the environment is a complex 3D problem. Although nice applications have been developed for the joint rendering of simulated wind flow and dispersion together with (photo-) realistic renderings of urban context [QZF*04] - even for virtual [KTM08] or augmented reality applications [HRR] - only very basic techniques are included in most commonly available visualization systems.

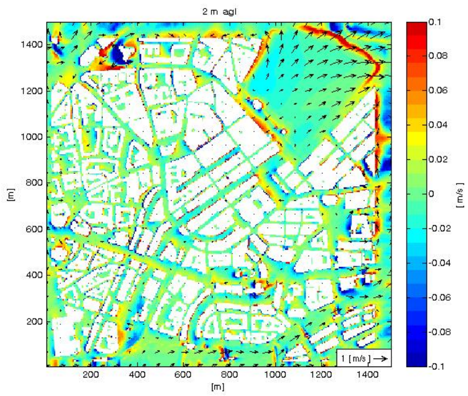

Figure 2: MITRAS data visualized using NCL.

2.1. MITRAS Simulation Model

The obstacle resolving micro-scale model MITRAS (MIcro-scale TRAnsport and Stream Model) is part of the M-SYS model system for the assessment of ambient air quality [Tru04]. Other microscale simulation models, such as ENVI-met[†], exist, but the architecture of MITRAS and its functionality are far superior to others. The parallelized micro-scale model MITRAS is coupled to the mesoscale model METRAS and can be used for simulations of wind and dispersion at different resolutions.

The domain size ranges between a few hundred meters (street canyons) up to a few kilometres (suburbs, parts of a city) horizontally, and a few hundred meters vertically (domain height). A 3D non-uniform grid allows for higher resolution in interesting areas, e.g. close to an interesting structure or to the surface, and at a coarser resolution in all other areas [Sch03] [Lop05]. Wind, temperature, humidity, cloud- and rainwater, as well as tracer concentrations are calculated from prognostic equations, pressure from the (diagnostic) anelastic equation. In the model, obstacles, such as buildings and trees, are resolved using the blocking approach for buildings, and the viscosity approach for vegetation. Additionally, also thermodynamic effects, including shading and heat transfer of and within buildings, are considered. The influence of unresolved land use characteristics (e.g. water, soil, grass) is accounted for in the surface fluxes, and orography by using a surface following model grid. The lateral model boundaries are open, inflow values may be prescribed. At the top, absorbing layers are employed. By using MITRAS model output in MECTM, concentrations of several pollutants (e.g. NOx, O3, SO2 , NH3, Pb, nitrate, sulphate), including their chemical transformations, can be calculated dependent on the sources (industry, power stations, household, traffic). Emission scenario studies can also be performed.

3. Visualizing MITRAS Data

The visualizations in this work were created using the commercially available software Avizo Green. Avizo Green was chosen as it specifically concentrates on the visualization of climate data sets, allows to import netCDF data files on a variety of different lattices, and is able to present (project) the data within its geographic context. Other visualization packages, such as Paraview, SimVis or Vapor, exist and are also employed at DKRZ for the visualization of climate data sets, but Avizo Green was selected, as it can be easily connected to drive our stereo backprojection system. This is important, as this is used together with the domain experts to look for variations and nuances in complex data sets.

The visualization goals for micro-scale data sets are similar to global climate simulations, and range from an interactive browsing for interesting features to a confirmatory visualization, and in the end, to the production of images an animations for communication purposes. In the following, the visualizations of three example data sets are discussed. This work only utilizes state-of-the-art visualization techniques, which have matured over the years and are available in free and commercial software systems such as Avizo and Paraview.

† http://www.envi-met.com/

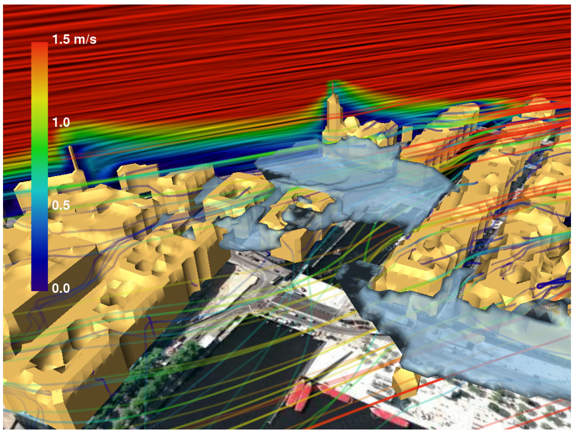

Figure 3: Wind Velocities and Cooling Effects.

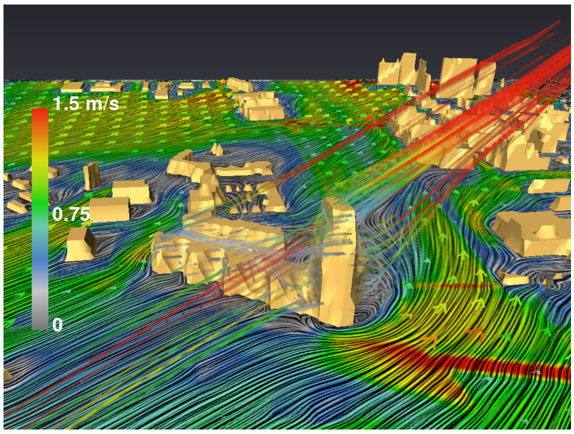

Figure 4: Visualization of Wind Velocity.

3.1. Inner City Ventilation

One important aspect in city construction is a proper ventilation of urban areas. This includes the exchange of air, and especially a sufficient ventilation of small structures, e.g. small streets, dead ends and closed courtyards. The regional climate, as well as a city's architecture, have both a huge influence on this [EPW10]. For example, if a big building is blocking the primary air flow direction, then areas behind it may not be affected from an air exchange. On the other side of the building, this might lead to strong downward directed winds, which can create strong winds at street level blowing dirt and sand around and in the air. Both events are undesirable, but can be considered during the design and construction phase of the building.

The first example visualizes a wind field in the inner city of Hamburg with a domain size of 1000 m x 1000 m. The data set is not time-varying, and contains an time-averaged wind field of one day. The right panel of Figure 1 shows an overview of the data with a LIC plane cutting through the wind field, color coding wind velocity that is ranging from 0 to about 1.5 m/s. Shown in yellow are the buildings as yellow iso-surface, which are derived from a 3D scalar field as a fixed boundary condition directly from the simulation. The LIC plane is used in interactive mode, to manually cycle through the velocity field to display the shadowing effects of buildings, e.g. the church in the back of 1.

Figure 3 shows another detail of the same data, again visualizing the wind field using streamlines and a LIC plane. Associated with wind, are also typical patterns in temperature and pressure change. A second iso-surface (transparent blue) visualizes cooler air that is drawn into the city from outside and results in a cooling effect. The temperature threshold for this iso-surface is set to 290.5 K. A transparent iso-surface was chosen, as it is a compact representation of the outer boundary for this temperature field, which does not entirely obstruct the view.

3.2. Difference Visualization

Depending on its architecture and position, individual buildings can have a huge impact on its local environment. In 2013, Hamburg hosts both the IGA (International Gardening Show) and the IBA (International Building Show), which are centred around climate and a climate-aware construction of urban areas. One of the newly constructed houses is the BSU building (Behörde für Stadtentwicklung und Umwelt – Agency for Urban Development and Environment), which is taller than its surroundings.

In this data set, the area of study is in the center of Hamburg-Wilhelmsburg. The domain covers an area of 2.25 km^2, and is centred around the new BSU building. The realistic orography, land-use data, as well as the buildings geometries are considered in the simulation. A non-uniform model grid has been employed with a total of $4.5x10^6$ grid cells. The approaching wind was 5 m/s from the south-west (235°), and the atmospheric stability was set to neutral. Due to the high rate of urban development, the impact of new buildings on the surrounding environment had to be investigated. Two simulation were carried out to explore wind conditions before and after constructing. The left panel of Figure 1 shows the differences between the two data sets, with the BSU building in the center, obstructed by the visualization. Areas marked in red perceive more wind, while areas in blue are less windy, due to blocking and shadowing effects.

The data also reveals many other interesting small scale features, as can be seen in 4. Here, turbulence behind the BSU building is depicted that might lead to strong winds in this area. The wind is visualized using color coded streamlines that pass by the new BSU building, the building itself is displayed using a yellow iso-surface. The LIC plane at the bottom is a cross-section through the velocity field, and highlights the orography resolving simulation of the model, which is clearly visible at the higher wind velocities on the three railway overpass, just right of the building.

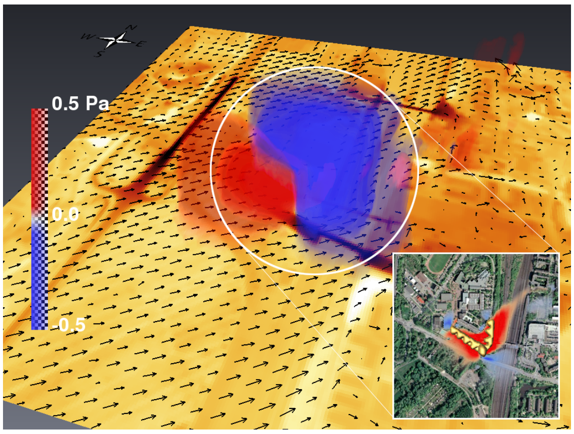

Figure 5: Pressure Differences caused by the BSU Building.

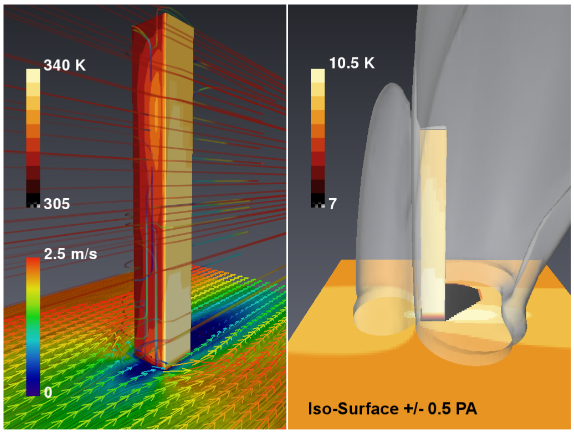

Figure 6: Wind, Temperature and Pressure Visualization.

Often also comparative visualizations are required, in which findings in one data set can be be compared with other data sets, or different variables. For example, changes in wind velocity are also visible in changes in pressure and temperature with similar patterns. Figure 5 shows pressure differences in Pa, in which pressure is visualized either in red (more) or blue (less). It shows, as expected, a higher pressure in front, and a lower behind the building. The buildings position can be seen from the inset at the bottom right. Additionally, a slice at the bottom displays the entire pressure field, in here lower pressure appears darker. Prominent are the railway overpasses, as well as the elevated highway on the left, which, due to their flatness, have a lower pressure. Overall, this visualization confirms the previous findings that were shown in Figure 1.

3.3. Individual Buildings

The third application analyzes the thermal interaction between buildings and its environment. In fact, climate in urban areas is influenced by buildings, not only in respect to wind but also thermally. Relevant processes can be the conduction of heat from warm indoor regions through walls and roofs to the environment or changed radiation fluxes compared to rural areas. MITRAS is extended to determine the surface temperature and the energy fluxes at building surfaces by considering short wave and long wave radiation, heat conduction to the buildings interior and sensible heat flux between surface and ambient air.

The left panel of Figure 6 shows a complex visualization of a single high-rise building in a cloud-free situation. The wind velocity and direction is visualized by a combination of color coded streamlines, vector arrows and a LIC slice. Additionally, the temperatures on the building's exterior are mapped to colors. The right panel shows the differences in ground temperature combined with iso-surfaces for the +/- 0.5 Pa pressure anomalies induced by the building. The wind field leads to a slight cooling of the air next to the irradiated walls and to an accumulation of warm air in the recirculation area at the downwind side of the building. Advantageous in these visualizations is that wind speed, temperature and pressure can be displayed at the same time, thus allowing to recognize processes and feedbacks between different meteorological variables more easily.

4. Summary and Conclusions

In this short overview, we have discussed several visualizations of micro-climate data sets. We have shown, how generally available visualization techniques can be employed to extract interesting features within the data, to aid the process of understanding, but also to visualize the impacts of an individual building on the climate of its surrounding environment. The added depth perception from 3D rendering, as well as the possibilities for a multi-parameter visualization provide a better understanding of the interactions between different meteorological variables. The data sets shown are moderately sized, but future simulations, however, with an increased spatial and temporal resolution, may be more demanding on the visualization requirements. Another important aspect is the verification of the simulation results, which can be performed using real models and one of Europe's largest wind tunnel installation[‡].

Acknowledgements

The work has been funded by KLIMZUG-NORD and Deutsche Forschungsgemeinschaft (DFG) within the Excellence Cluster CliSAP (EXC177). The numerical models are using digital terrain models, ATKIS-data, for Hamburg, the Digitale Stadt-Grundkarte (DSGK), as well as 3D-urban model data (LoD 2) as input. The computations were carried out at DKRZ.

‡ http://www.mi.uni-hamburg.de/

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