Estimation of sky view factor in complex environment as a tool for applied climatological studies

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Abstract

Graphic processors can be implemented in computation models, e.g. in three-dimensional flow visualization. Another possibility going a step further, and propose modern graphics hardware to be used as general-purpose vector computers. These ideas and approaches use a cheap mass technology to solve specific problems. This technology and way can be applied for climate conditions or climate relevant parameters in urban scale or complex environments. Following benefits are provided from the new model: (a) short computing time and (b) low costs though the use of open source frameworks. We chose the implementation of sky view factor (SVF) for each point in a complex area, given by a digital elevation model (DEM) and urban obstacles (OBS) in order to quantify relevant climatic conditions in urban and complex areas.

1. Introduction

We show how 3D hardware can be used to improve modeling of sky view factor (SVF) in complex urban environments. Modelling of climate processes in urban areas is still challenging, some authors find it to be one of the most difficult areas in climatology (MATZARAKIS, 2001; KUTTLER, 2004a, b). The visible horizon is modified by surrounding urban structures and obstacles, radiation fluxed are altered. This results in alteration of a location's bioclimate, as radiation fluxes are one of the main factors of thermal comfort equations. The modification of urban structures can be estimated by measurement or calculation of sky view factor (MATZARAKIS *et al.*, 2007). SVF is one of the most relevant input parameters for estimating radiation fluxes in complex environments.

Powerful yet cheap graphic processors have recently been employed to implement computation intensive models, e.g. in three-dimensional flow visualization (CUNTZ *et al.* 2007). Other researchers use modern graphics hardware as a general-purpose vector computer (THOMPSON *et al.,* 2002). The idea is the same: a cheap mass technology is utilized to solve specific and specialized problems. This approach can be applied in climate or urban climate modelling as well.

We start with an overview of traditional methods of calculating SVF. A short chapter on different methods of utilizing graphics hardware follows. We then present the new efficient SVF model SkyHelios to calculate continuous SVF. In two examples, one vector, and one raster based, the chances and drawbacks of both approaches are shown. Finally the possibilities and limits of the new model are examined and discussed.

2. Methods to estimate SVF

Measurement and calculation of SVF has some history in urban climate research (STEYN 1980; JONHSON & WATSON 1984; WATSON & JOHNSON; 1987, 1988; HOLMER, 1992), though is still subject to intensive research (LITTLEFAIR, 2001; GRIMMOND *et al.*, 2001; RATTI *et al.* 2004; MATZARAKIS *et al.,* 2007; GÁL *et al.,* 2008).

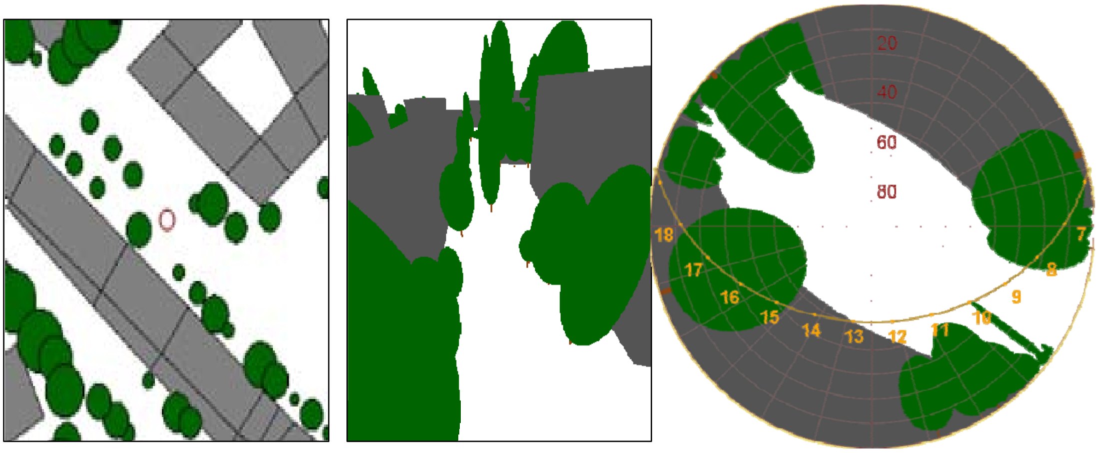

Fig. 1: Example of a modelled sky view factor image and its relation to the surrounding urban structure. a) view from top. b) birds eye view on the scene. c) sky view image. Sunpath shown for 48°N mid of April

The most traditional way to measure SVF ist to take a 180° fisheye photograph (CHEN & BLACK, 1991, LITTLEFAIR, 2001). Usually the camera sits on a tripod at 1 m height, with a fisheye lens looking into the sky. Different ways have been examined to asses sky view information from the photo, including scaled paper paper (JOHNSON & WATSON 1984; FRAZER *et al.,* 2001), computer programs helping to manual track the sourroundings (HOLMER, 1992; CHAPMAN *et al.,* 2001; HOLMER *et al.,* 2001; TELLER and AZAR, 2001; MATZARAKIS *et al.,* 2007), and fully automatic tracking of the sourroundings by software (CHAPMAN *et al.,* 2001; BRUSE and FLEER, 1998). Augmented with digital cameras, this last approach can lead to a very quick assessment of SVF at a particlar spot.

Instead of taking photographs, sky view factor can be calculated from digital models of the environment. (BRUSE and FLEER, 1998; TELLER and AZAR, 2001; MATZARAKIS *et al.,* 2007). Calculation of SVF is based on knowledge of each angle element of the hemispheric environment and associated elevation (in connection with produced shadow) angle β and azimuth angle α. Accordingly, the sky view factor Ψs can be assumed to be the sum of all this angle information over the whole hemispheric environment.

$$\Psi_s = 1 - i \sum \sin^2 \beta_i \left(\frac{a_i}{360°} \right)$$

Caclulating SVF has the benefit that is it no longer required to actually go out and take a picture, a process in which a lot of errors can occur. Instead the models, e.g. RayMan (MATZARAKIS *et al.,* 2007), allow for quickly assessing SVF at different locations. Some models even allow for calculation of continuous sky view factor, i.e. the spacial distribution of sky view factors in an area or whole city (GÁL *et al.*, 2008). Most models are based on representations of buildings (SOUZA *et al.* 2003) or digital elevation models (DEM) (GÁL *et al.*, 2008), allowing only for simple shaped building and flat roofs.

A few models are based on the idea of obstacles, allowing for modelling non-flat roofs and trees as well (MATZARAKIS *et al.,* 2007). Including non-flat roofs and trees into modelling seems to be cruical at least for modelling central european cities.

Fig. 1 shows the connection between surrounding structures and a SVF image. The sky view factor can be easily caclulated from it by dividing the area of the image that is not covered by obstacles by the total image area. Sky view factor in the example in Fig. 1 is 0.31, i.e. only 31 % of the sky is visible. The sunpath is shown for a latitude of 48° mid of April. Even though the sun is above the horizon from ca. 6:00 am to 7:00 pm, the selected location gets direct sunshine only from ca. 8:15 am to 1 pm.

3. Utilizing graphics hardware for modelling

While graphics hardware has primarily been developed to perform graphics display on a personal computer, modern 3D-graphics hardware has reached a level at which it can be seen as a general purpose vector computer (THOMPSON et al. 2002). A vector computer is one that performs the same operation on multiple data sets very efficiently. Therefore modern 3D-hardware has a lot of potential appplications in modelling, e.g. three dimensional climate flow data visualization (CUNTZ *et al.* 2007). More possibilities arise, when one does not only visualize modelling results, but reads results back from the graphics hardware. When applicable for vector processing, time intensive modelling algorithms can be transferred on the graphics hardware, with the result of a substancial reduction in processing time in the order of several magnitudes. We transferred the SVF calculation algorithm on the graphics hardware, making use both of the graphics rendering capabilities of the hardware as well of its function as a general purpose vector computer.

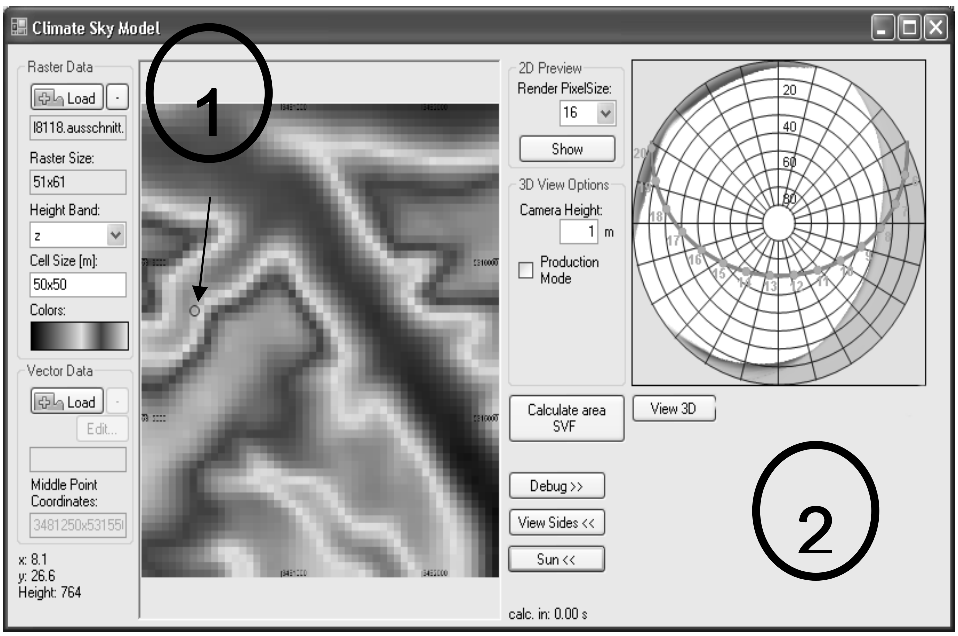

Fig. 2: Screenshot of SkyHelios and view of the sky view factor image (based on topographical data) with sun locations for Freiburg end of July. Arrow indicates selected location for the Sky View Factor

4. Raster and vector calculations with SkyHelios model

Fig. 2 shows am image of the user interface of SkyHelios. A digital elevation model (DEM) has been loaded and is shown for orientation in the left part of the sceen. A circle indicates current position for the calculation of the sky view factor image and SVF. The sky view factor image is shown on the right, overlaid with the sun positions at a latitude of 48° N for a date end of July. When "production mode" is checked, the SVF for the correspodung location is immediately calculated. Since making use of 3D graphics hardware, calculation of SVF with SkyHelios is fast. There is no delay between selecting the location and display of resulting SVF.

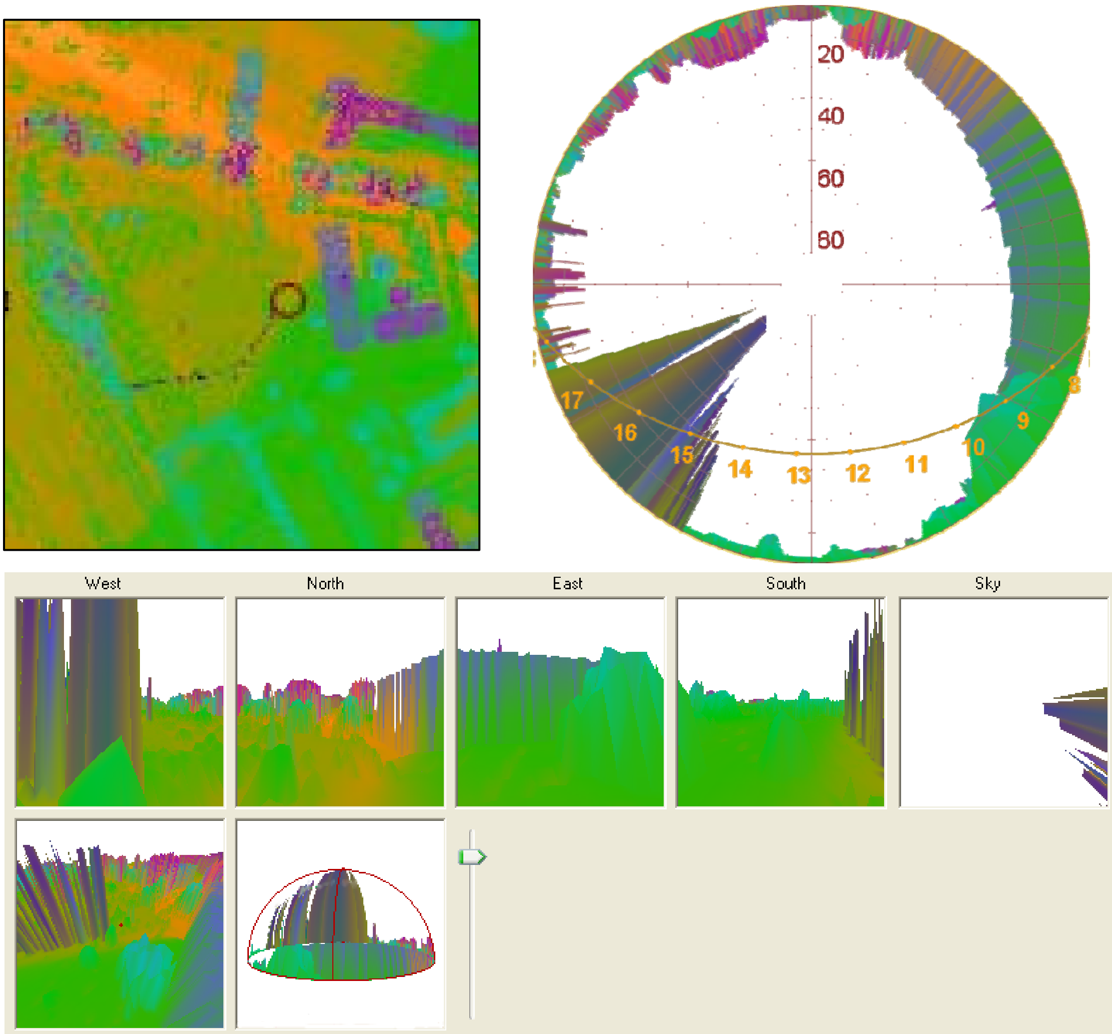

Fig. 3: A location in Freiburg, Germany, based on laser data. Top view, sky view factor image for a tripod height of 10 m and corresponding bird's eye view as well as view into all for directions and the sky

Fig. 3 shows sky view factor calculation of a location in Freiburg, Germany. The calculation is made with a DEM based on laser data with a resolution of 1 m. The top view image shows a building to the east, and a row of probably trees to the west. There are more building and trees to the north and south. The corresponding SVF image was calculated for a tripod height of 10 m, giving a SVF of 0.69. Using a laser DEM for calculation of sky view factor allows for a rapid estimation of sky view factor for a whole city (GÁL *et al.*, 2008). The sky view factor image and more so the side views and the bird's eye view though clearly show drawbacks of using raster DEM. While the building to the east seems to be quite well modelled, what are probably trees appears to be hight but narrow "needles" looking into the sky. Their shape e.g. trunk and crown can not be modelled with a DEM based approach. The vector based approach, shown on Fig. 1, allows for modelling of trees and non-flat roof buildings as well. It has the drawback that vector models of cities are not as readily available as are DEM.

5. Discussion and conclusion

We show how computer graphics hardware can improve climate 3D modelling in applied climatology for complex environments. Several visualization techniques can help understanding of possibilities and limits when modelling SVF. SkyHelios allowes to export results for dispay in the climate mapping tools (MATUSCHEK and MATZARAKIS, 2010). Frequently-used data formats (i.e., laser or satellite data) are supported. Direct implementation of RayMan obs files (MATZARAKIS *et al.*, 2007) is an advantage, and furthermore the combination of raster and vector approaches is possible.

The visualization of morphological factors (especially in urban areas) helps to understand micrometeorological processes. The sky view factor expresses the morphological factors for a specific site in one single value, and therefore allows for an estimation of relevant climatological information. We plan to implement the spatial extension of radiation fluxes and the mean radiant temperature with very high resolution. In order to get radiation fluxes, many additional features (such as shadow generation and sunshine duration) are required from the morphological option.

SkyHelios is freely available and can be requested from the authors.

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