Sunrise on the Klamath: an ArcObjects application for determining topographic sunrise and sunset

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Introduction

The duration of direct solar illumination on a watercourse is a useful component for hydrologic temperature modeling in topographically varied regions. Researchers at the University of California, Davis, developed an ArcMap macro using ArcObjects and VBA to estimate the duration of direct illumination and sunrise/sunset as determined by the surrounding topography for the lower Klamath River in Oregon and California. The model is based on sequential raster hillshading, in ESRI ArcGIS Spatial Analyst (v9.0), with computed shadows driven by an adaptation of NOAA's solar calculator. The time and spatial resolution can be modified to meet user needs and processing capabilities. Required inputs are a Digital Elevation Model (DEM), sample points, the date for the model run, and a latitude and longitude for the solar calculations. The output is a geodatabase table containing the sample point IDs, sunrise and sunset times and the duration of direct illumination.

The objective of this project is to develop a model to predict the time of first and last direct solar illumination of a set of sample points based on surrounding topography and global position and the date of interest. We used digital elevations from the United States Geological Survey (http://seamless.usgs.gov) at a nominal ground cell resolution of 10m. Sample points were provided by Watercourse Engineering, Inc.

Methods

General methodology

The primary driving algorithm within the model is HILLSHADE (ESRI; Redlands, CA) with the "shadows" option active. HILLSHADE produces a raster grid that considers both local illumination angles and shadows based on a raster surface and parameters for the position of the sun (angle of incidence and azimuth). The output contains values from 0 to 255 with areas of complete shadow having a value of 0. Values 1 through 255 indicate increasing levels of direct illumination based on incident light. The challenge is to calculate the elevation and azimuth repeatedly throughout the day in nominal increments. The National Oceanic and Atmospheric Administration (NOAA) Solar Calculator Internet-based tool was adapted to fit the needs of calculating solar position. We converted the source code for the calculator from Java to a Visual Basic for Applications (VBA) module. Given the solar calculator, a set of sample points and the DEM, we developed an iterative application that runs a series of HILLSHADE operations immediately followed by sampling at each point of interest. The model creates a table in the personal geodatabase containing the Sample Point IDs and the first and last time of direct illumination. Iterative time steps are user-selected at 15, 30, or 60-minute intervals.

Data preparation

All spatial data, with the exception of the DEM, must be feature classes within the same personal geodatabase. As presently configured, a layer representing the physical geographic boundaries of the study area needs to be created with a single polygon feature. This polygon surrounds all of the sample points and is projected into a Geographic Coordinate system (World Geodetic Survey 1984). The centroid

of this polygon provides the latitude and longitude used by the Solar Calculator. The DEM must have the same vertical units as the linear unit within the DEM's spatial reference (i.e., x, y, and z measures must be in the same units) or erroneous results will be returned. In the case of our Klamath model runs, the native USGS Seamless Data Distribution System (SDDS) DEM was clipped to a 25km buffer of the Sample points provided by Watercourse Engineering, Inc. The 25km buffer reduced the DEM to a manageable size for projection from the SDDS coordinate system to Universal Transverse Mercator (Zone 10 North; North American Datum 1983) while maintaining the high ridges that provide shade to the main stem. The sample points may be generated in any manner desired, but they must be simple points with a field called "Sample_pt" that contains a unique numeric identifier.

Module Details

Solar Calculator: The solar calculator is a translation of NOAA's Solar Position Calculator into a VBA module. This conversion produces results that differ from NOAA's online results by not more than 0.01 degrees for both elevation and azimuth. Required inputs to the Solar Calculator are the geographic coordinates of the point for which the calculation will be run (normally the centroid of a polygon containing the sample points) in decimal degree latitude and longitude. Other required inputs to the solar calculator are: the local time to be calculated in 100ths of an hour since midnight, the date, the UTC Correction (time correction to Universal Time), and whether a daylight savings adjustment is necessary. The results are the altitude and azimuth (both in decimal degrees) of the sun at the time and date specified. All numeric variables are maintained as Double data types with the exception of some inputs (day, month and year from the user entered date).

Engine: The Engine module is a collection of general utility functions and sub procedures created to ease the general operation of the model. These functions include creating an output table, populating the table with sample points, testing and verifying data to be inserted into the table and making the actual insertion.

Main module (frmMain). The Main form serves both to collect the information needed to run the model and as the main script to execute it. This can be logically broken into three main parts: the user interface, the input validation, and the model.

The user interface is a simple interface that picks the layers from within the map document's table of contents and presents them to the user as choices in dropdown menus appropriate to the layer's type. Drop down menus are also provided for selecting the UTC adjustment, Daylight savings status, Start Time, End Time and Time interval. A Text box is provided for entering the date for the model run.

On initialization of the Main form, raster layers are added to the DEM selection menu, point layers to the sample point menu, and polygons to the boundary layer menu. All of the other menus are populated with a static set of choices. The Daylight Savings adjustment is a Boolean selection. UTC adjustment is populated with values from 4 to 10 covering a majority of North American options. Start and end times are provided as a means to reduce the duration for which the model runs during the day entered in the date text box. The default is to run for the full day (midnight to midnight local time) and in most cases that is what should be run. The time interval determines the time step throughout the day in 100ths of an hour. The date is validated based on the VB function IsDate (Microsoft) and is treated from that point on as a Date variable type. All other entries either require no validation, or are assumed to be datasets in the correct format.

Following input validation, the primary script for the model begins. The table of contents is parsed to gain references to the Sample Point layer, DEM, and the Boundary Layer. An output table name is automatically generated based on the date and time that the model is run and the date the model is run for and is created in the personal Geodatabase in which the Sample point layer is stored. The table is then populated with the Sample_pt values from the Sample Point layer. Fields for the time of sunrise and

sunset are assigned a default value of -999, or null. The Boundary Feature's centroid is queried to provide the geographic point for use with the solar calculator.

The first time step is calculated based on the Start Time selected by the user. The first time step, lat, long, UTC adjustment and date are submitted to the solar calculator, which returns the sun's altitude and azimuth. If the altitude is less than 0 (i.e. the sun is below the horizon) the model moves to the next time step (current time plus the time interval selected by the user). If the altitude is greater than 0 a HILLSHADE with the shadows option is executed. This is followed by sequentially querying the hillshade result with each of the sample points. If the returned value is greater than zero the current time step is written to both the Sunrise and Sunset fields in the table for the sample point. Following completion of the sampling process, the next time step is processed similarly. If values returned from the sample point query on the hillshade are greater than zero, the time step is written to both the sunrise and sunset fields unless there is a preexisting (<> -9999; or not null) value in the Sunrise field. If the Sunrise field already has an entry, it is left intact and the value is written only to the sunset. This looping continues until the End Time is reached or the sun drops below the horizon.
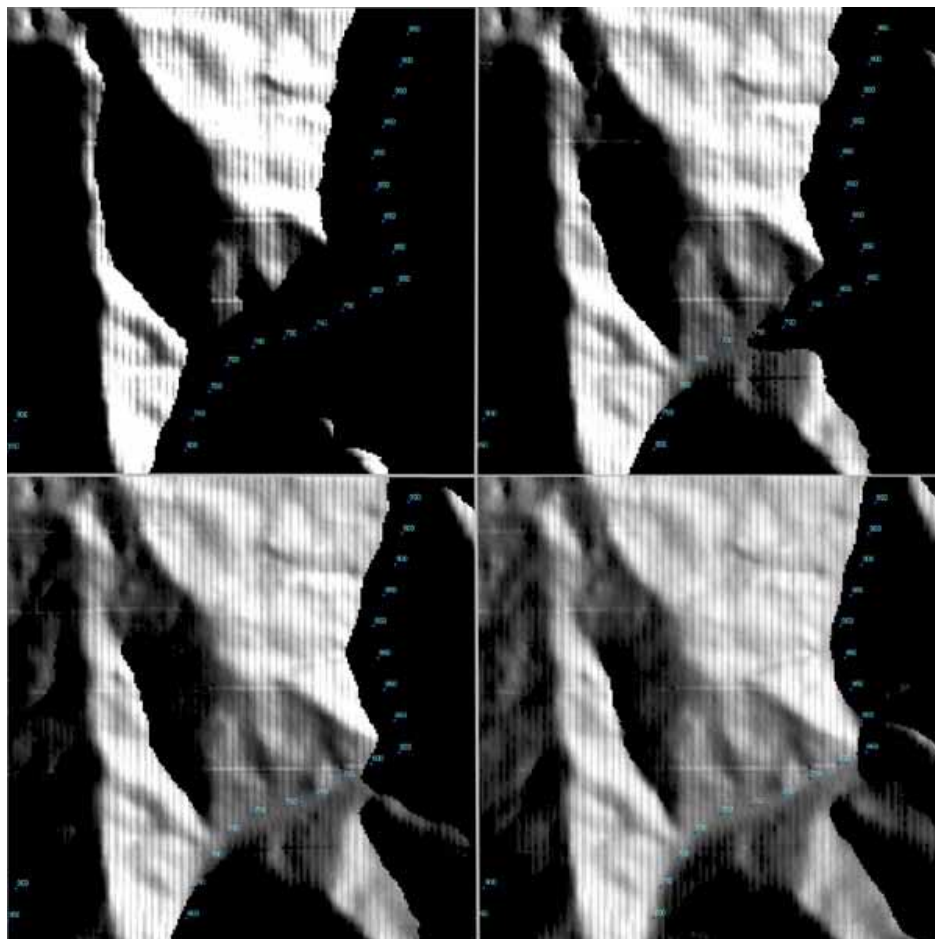
A sunrise: The upper left image is the 6:30am time step. Upper Right is 7:00am. Lower left is 7:30am and lower right is 8:00am. Note how the shadow recedes and more of the sample points in the valley bottom are illuminated.

Output

A table is created that contains the Unique identifier from the Sample_pt layer, the time step in which the point first received direct illumination and the time step in which it last received direct illumination. The

table can then be joined to the layer for display purposes and symbolization, or it can be processed independently to produce other desired information (the difference between the times of first and last illumination).

Results joined to the sample points and displayed with sunrise, sunset and the difference between the two (Times are in hundredths of an hour).

Results

We tested the model against real world conditions in each case the model performed well. A visual observation of sunrise and sunset at Tobacco Flats, near Convict Lake on the Eastside of the Sierra Nevada, provided results within 15 minutes time of predicted illumination times. A subsequent and more thorough check at Lake Berryessa, about 25 miles from Davis, California, demonstrated sunrise accurate within the 15 minutes of the model run's resolution. 9 points were selected in rugged terrain in the viewshed at the south end of Monticello Dam. Eight of the points were easily identifiable in the field. All eight identifiable points first received direct sunlight in the 15 minutes preceding the time indicated in the model. We were unable to determine whether or not illumination began at the correct time at the remaining and only west-facing location. The first visible illumination on the slope was at 7am and continued to spread across the slope until 8am when virtually the entire area that contained the test point was illuminated.

Sunrise on Lake Berryessa at 7:37 AM. Not the little point of sunlight. The model predicted the first direct illumination by 7:45.

Note that the results have not been extensively field verified, but when joined to the Sample Point layer based on the Sample_pt field in both tables makes intuitive sense. And when multiple model runs are merged, the duration of illumination throughout the year demonstrates the expected annual variation.

Results are highly dependent on the quality of the DEM being used. Quality of resulting data from the projection of rasters is a well-known and well-documented concern. The model implementation for the Klamath Basin involved projecting a USGS DEM from decimal degrees (WGS 1984) to Universal Transverse Mercator (Zone 10 North; North American Datum 1983) using nearest neighbor interpolation. There was no attempt to either identify or quantify errors associated with projecting these raster data; however, resampling artifacts should be expected. Our original DEM was reprojected prior to ArcGIS service pack 3, resulting in a nearest neighbor interpolation being used instead of the selected cubic convolution.

Processing time can also be a prohibitive factor. A half-hour-interval model for a sizeable chunk of the Klamath River Watershed (10m DEM), using just under 3000 sample points, took approximately 8 hours to run on a Pentium 3, 1.6Ghz, computer with 738Mb of RAM. Upgrading to a hyperthreading 3.2Ghz Pentium 4 with 1GB of ram reduced the run time to just under 3 hours.

Performance of this model outside the geographic confines of North America is completely untested. Only limited field verification of any sort has been initiated. Parameter testing has not been conducted intensively outside of the Klamath Basin proper.

Discussion

The Klamath River flows through a mountainous region of northern California. Efforts to quantify the impact of topographic shading on water temperature were explored with a simulation model.

Topographic shading information developed by the Information Center for the Environment at UC Davis was incorporated into the Klamath River flow and water quality model as a separate input file. The hours of sunrise and sunset for all nodal values were read in on the first and fifteenth of each month, with values for intermediate days estimated through linear interpolation within the simulation model. Linear interpolation of sunrise and sunset values on approximately 15-day intervals was deemed and acceptable estimation because the model simulations were on an hourly time step. The water quality model used by Dr. Michael Deas was modified to incorporate the effective sunrise and sunset due to topographic shading in the solar radiation calculations, effectively reducing the day length from theoretical sunrise and sunset (i.e., "flat earth" sunrise and sunset).

Water temperature simulations incorporating topographic shading were completed for the Klamath River from near Klamath Falls to near the mouth - a distance of approximately 250 miles (four reservoirs occupy a total of approximately 34 miles of this distance and were represented with a different water quality model, CE-QUAL-W2, that has a separate shading algorithm). Comparing the without and with shade simulation results indicate that topographic shading predominately affected water temperatures at specific locales along the river reach and that such reductions were modest (typically well less than 1oC). Reduced temperatures, i.e., thermal benefit, did not accumulate in the downstream direction because topographic shading did not consistently shade the river in space or time. Thus, reaches that were shaded showed modest temperature reduction over the no-shade condition, but when waters flowed downstream into reaches without appreciable topographic shading, water temperatures quickly warmed to levels equivalent to the no-shade condition. Intuition would lead one to believe that topographic shading would play a larger role in such a mountainous region, but results indicate that topographic shade on the Klamath River has a small impact on water temperatures. Further studies are planned to ascertain the seasonal impacts of topographic shade, particularly during periods when solar altitude is not at the maximum annual value.

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