Enlightenment for Mapping Systems

solar radiation modeling looks to the sun for answers*

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Sunshine, which supplies the energy needed for life on Earth, plays a key role in energy and water balance by heating the earth's surface, evaporating water and generating weather. It influences critical local factors such as air and soil temperature, humidity, moisture and snow melt.

Solar radiation affects global climate patterns and local crop growth conditions. The sun and earth's geometries determine patterns of incoming solar radiation, called "insolation," on a global scale. Topography, vegetation, human structures and atmospheric conditions affect insolation at the local level.

Insolation maps, which show local effects, are valuable for agriculture, forestry and resource management. New tools that use geographic information systems (GIS) help construct insolation maps based on spatial modeling.

Insolation is difficult to measure due to variations in time and spatial location. Typically, insolation is measured using sensors at monitoring stations. However, for most other locations these measurements are unavailable. Sensor measurement interpolation and extrapolation cannot account for spatial and temporal variation.

Models measure up

Solarflux, developed in 1992 by Paul Rich and William Hetrick of the University of Kansas, and similar models that simulate shadow pattern influence on insolation, has been used by researchers to produce insolation maps. However, these models are available only for use with high-end GIS software and computers. They also offer limited capabilities and perform calculations slowly, taking up to a year to calculate an insolation map.

Newer spatial insolation models provide better accuracy, faster calculation, broad availability and improved flexibility using a calculation algorithm called "upward-looking viewshed analysis." These models account for elevation, surface orientation, sky obstruction by surrounding topographic features and atmospheric conditions.

Spatial models such as TopoView and the Solar Analyst, recently developed by Rich and Pinde Fu of University of Kansas, produce insolation maps using digital elevation models (DEMs) for input. DEMs are composed of cells arranged in rows and columns to represent location. Each cell contains a value representing elevation. The insolation types calculated for each cell are direct and diffuse radiation. To make the calculations, upward-looking viewsheds are constructed based on geometry from the DEMs.

Viewsheds are maps of visible locations.

Upwardlooking viewsheds are maps of sky directions visible from the location where insolation is to be calculated. The concept of calculating insolation using upward-looking viewsheds originated'from the hemispherical, or fisheye, photography technique pioneered by foresters and forest ecologists.

However, instead of using a special camera to obtain an upward-looking viewshed for a location, TopoView and the Solar Analyst use DEMs to calculate viewsheds for each location in an area. It takes billions of calculations to build an insolation map and the process involves these main steps:

- An upward-looking viewshed is constructed by searching in each direction of a location. This method determines the angle above the horizon where the sky is obstructed by topographic features.

- The viewshed is placed over a sun map, which depicts the sun's path, to calculate direct radiation. Each position along the sun's path corresponds to a time of day and year, and an amount of direct insolation originating from that sky direction. Obscured sky directions along the sun's path correspond to times when the location in shadow. Direct radiation can only originate from visible sky directions.

- The viewshed is then overlaid on a sky map to calculate diffuse radiation. Sky maps depict the entire sky and a known amount of diffuse radiation originates from each sky direction. Obscured sky directions correspond to directions from which diffuse radiation is blocked. The viewshed on the skyrnap allows for measuring only diffuse radiation originating from visible sky directions.

Calculations account for latitude, elevation and orientation of the receiving surface, and atmospheric conditions. Repeating the process for all DEM locations produces a complete insolation map.

The biggest insolation differences are in regions with high topographic diversity but they are also observed in other terrain.

As part of a project involving microclimate and vegetation near Rocky Mountain Biological Laboratory (RMBL) in Gunnison County Colo., TopoView and the Solar Analyst were tested and used to build soil temperature maps. The goal was to examine relations between microclimate and vegetation distribution, and to predict potential changes under various climate scenarios.

A digital elevation model for the study area was constructed by combining various U.S. Geological Survey DEMs. Predicted viewsheds calculated from the DEMs corresponded with hemispherical photographs taken at locations in the field. Resulting insolation maps showed high spatial variability.

Different locations in the landscape can have varied temporal insolation regimes, which affect factors such as soil temperature and moisture. Insolation, through its effect on local heating in daytime is a key factor in determining soil temperature. The biggest impact is on temperature increase - maximum minus minimum - through the day.

Soil moisture and air relative humidity are negatively related to insolation, while air temperature and potential evapotranspiration are positively related. Understanding insolation is a component for microclimate models used to explain vegetation patterns.

Far-reaching benefits

Spatial insolation models have been applied to a diverse set of applications ranging from solving resource management problems to basic research. Insolation maps are used for siting vineyards, designing ski resorts and evaluating waste sites. Spatial variation of insolation helps determine habitat suitability for native and non-native species. For example, habitat and annual population density variation of the endangered Bay Checkerspot Butterfly, *Euphydryas editha bayensis*, in California was determined using insolation and rainfall data.

Landscape-scale insolation studies on whole watersheds have helped in understanding energy and water balance. Insolation differences were a main factor in determining temperature differences among Antarctic lakes.

Plant productivity is influenced by ambient temperature, moisture availability and photosynthetically active radiation levels, which relate to insolation. Many forest and crop models might benefit from incorporating a spatial insolation submodel.

Spatial and temporal insolation variation benefits crop yield, irrigation management and determining crop zones, non-point source pollution, fire risk, wildlife habitat characterization and climate change scenarios. Spatial solar radiation models can also be applied to remote sensing for correcting topographic influences.

Applications involving energy or water balance could benefit from detailed insolation analyses. Better understanding of solar radiation as a resource can enable more efficient use of other resources and facilitate management decisions.

Computers and new generation spatial insolation models have made it practical to build such detailed maps. Models such as TopoView and the Solar Analyst provide tools for diverse applications in agriculture and forestry as a cost-effective means for researchers and resource managers.

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This upward-looking hemispherical photograph was taken at a weather station.