Spatial Modeling using geographic information systems

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Abstract

Introduction

Remote sensing data for managing agricultural water resources is becoming a common occurrence. Remote sensing refers to the use of sensors to obtain data about an object located some distance from the object. A remote sensor may be located several meter or thousands of kilometers away from an object. For example, a farmer can use an infrared thermometer to estimate the plant canopy temperature. Surface temperatures can also be obtained from satellites, such as the U.S. National Atmospheric and Oceanic Administration's (NOAA's) Geostationary Operational Environmental Satellites (GOES), which is located approximately 35,000 km from the Earth's surface. Another example of remote sensing is Doppler radar, which can be used to estimate rainfall.

Remote sensing has been used for numerous agricultural applications, including estimates of plant canopy temperature (Harmsen et al., 2009), vegetation indices (Mecikalski and Diak, 1999), solar radiation (Paech et al., 2009 and Otkin et al.,1995, Harmsen et al., 2014a), photosythetically active radiation (Saha, 2003), soil moisture content (Ramirez Beltran et al., 2010), inundated area (Smith, 1997), potential evapotranspiration (Narasimhan,2003), energy budgets (Harmsen et al., 2014b), land cover analysis (Aggarwal, 2003), wet lands encroachment (Klemas, 2011), soil and fertility analysis (Numata et al., 2003), water and wind erosion (Saha, 2003), Crop growth (Dadhwal, 2003), etc.

Numerous remote sensing algorithms have been developed for the surface energy budgets in the crop canopy for estimating evapotranspiration. The Surface Energy Balance Algorithm for Land estimates the surface heat fluxes based on spectral satellite measurements (Bastiaanssen et al., 1998). The SEBAL algorithm uses visible, near-infrared and thermal infrared data obtained from satellites and ground stations. SEBAL uses an iterative and feedback-based numerical procedure to deduce radiant, latent and sensible heat fluxes. By multiplying the latent heat flux by the latent heat of vaporization, the actual evapotranspiration is obtained. As the SEBAL methodology is based on data from polar orbiting satellites, it is capable of estimating instantaneous or daily average fluxes. The SEBAL method has been applied in Turkey by Bastiaanssen (2000), at several locations throughout the U.S. (e.g., Thoreson et al, 2009; Allen et al. 2001, Allen et al., 2007)

Using ET, derived from the energy balance method, along with rainfall data, it is possible to perform a pixel-by-pixel water budget. Water budgets performed using remote sensing have several important advantages over traditional methods such as, the higher spatial resolution allows the incorporation of detailed land information (e.g., cover, soils, elevation), solar radiation and rainfall information; numerous watersheds can be evaluated simultaneously; and operational remote sensing data (i.e., data that is made available by NASA or NOAA on an hourly or daily basis) can be frequently updated and made available to the public. Referring to a drought metric based on remote sensing, Anderson et al. (2007) assert that the advantage is that ground-based data needs are reduced, improving spatial detail and portability to areas without extensive weather data collection capability. Regarding the advantages of using remote sensing technology for solar radiation, Sumner et al. (2008) listed large spatial coverage, relatively high spatial resolution, and the availability of data in remote, inaccessible regions and countries that may not have the means to install a ground-based pyranometer network. In the case of Puerto Rico, for example, currently there are only 10 to 20 functional pyranometers in the island. The GOES Satellite-based, solar radiation product described by Harmsen (20014b) provides solar radiation at 1-km spatial resolution, and therefore, simulates approximately 9000 virtual pyranometers distributed over the surface of the approximately 9000 km^2 island.

Several water budget models have been reported in the literature, which rely on remote sensing data. Vörösmarty et al. (1998) applied a water balance model (WBM) over the contiguous United States (0.5^o grid resolution) as part of an evaluation of reference evapotranspiration methods at a monthly time scale, and to evaluate possible implications for global-scale water balance and terrestrial ecosystem modeling. This model has been used in a study of global water resources, with an emphasis on vulnerabilities influenced by global climate change and population growth (Vörösmarty et al., 2000). The WBM model was applied by Fekete et al. (2002) to evaluate global river discharges. In this study, measured river discharge data were used to adjust runoff values using the simple relation:

$$R_c = \xi_{si} R_{wbm} \quad (1)$$

$$\xi_{si} = R_{oi} / R_{wi} \quad (2)$$

where R_c is the corrected runoff [L/T], ξ_{si} is the runoff correction coefficient, R_{wbm} is local (i.e., grid cell) annual WBM runoff [L/T], R_{oi} is mean annual observed interstation runoff [L/T], and R_{wi} is mean annual WBM runoff for the is interstation area A_{si} [L^2].

WBM obtains actual evapotranspiration (ET) by assuming that it is a fraction of the potential evapotranspiration (ET_p), representing an upper limit, and that the fraction is a function of the soil dryness (Federer et al., 1996). Actual evapotranspiration estimates were validated against "measured" actual evapotranspiration values. The "measured ET was obtained by assuming that the annual soil moisture storage change is negligible and measured evapotranspiration is equal to precipitation minus long-term measured stream flow.

Smaller scale models are useful for water resource managers at watershed and subwatershed scales. Alemaw (2012) used the GIS-based Hybrid Atmospheric and Terrestrial Water Balance (HATWAB) model at a monthly time scale to evaluate water resources of the Limpopo and Congo basins in Africa. The GIS raster grid spacing of the model was 9.2 km (0.0833^o).

Harmsen et al. (2010) developed the GOES-Puerto Rico Water and Energy Balance (GOES-PRWEB) algorithm. They used a methodology similar to Yunhao et al. (2001) to calculate the energy balance and to estimate actual ET in Puerto Rico. Daily integrated solar radiation estimates are developed from GOES visible data at 1-km resolution over Puerto Rico. The methods of Gautier and Diak (1983), Diak et al. (1996) and Paech et al. (2009) are utilized, with validation of the solar insolation provided in Otkin et al. (1995), Mecikalski et al. (2011) and Harmsen et al. (2014). Rainfall is obtained from NOAA's Doppler Radar (NEXRAD). Surface runoff is estimated using the Natural Resource Conservation Service (NRCS) Curve Number (CN) method (Fangmeier et al., 2005). Deep percolation or aquifer recharge is assumed to be any water that exceeds the soil field capacity. On those days in which aquifer recharge occurs the final soil moisture is assumed to be equal to the field capacity. If the soil moisture does not exceed the field capacity then no recharge occurs. The model is operational in the sense that it is automated and provides a suite of 25 hydro-climate variables each day, which are available to the public via a web site (http://pragwater.com).

Examples

In this section an example is given in which remotely senses solar radiation data is used in combinations with other meteorological data, to estimate the water budget in Puerto Rico using GOES-PRWEB. Figure 1 and 2 show examples of the energy and water balance components, respectively, for February 1, 2014. Image data for twenty-five hydro-climate variables are available on a public website (http://pragwater.com/goes-puerto-rico-water-and-energy-balance-goes-web-algorithm/). Archived images are available from January 2009 through the present.

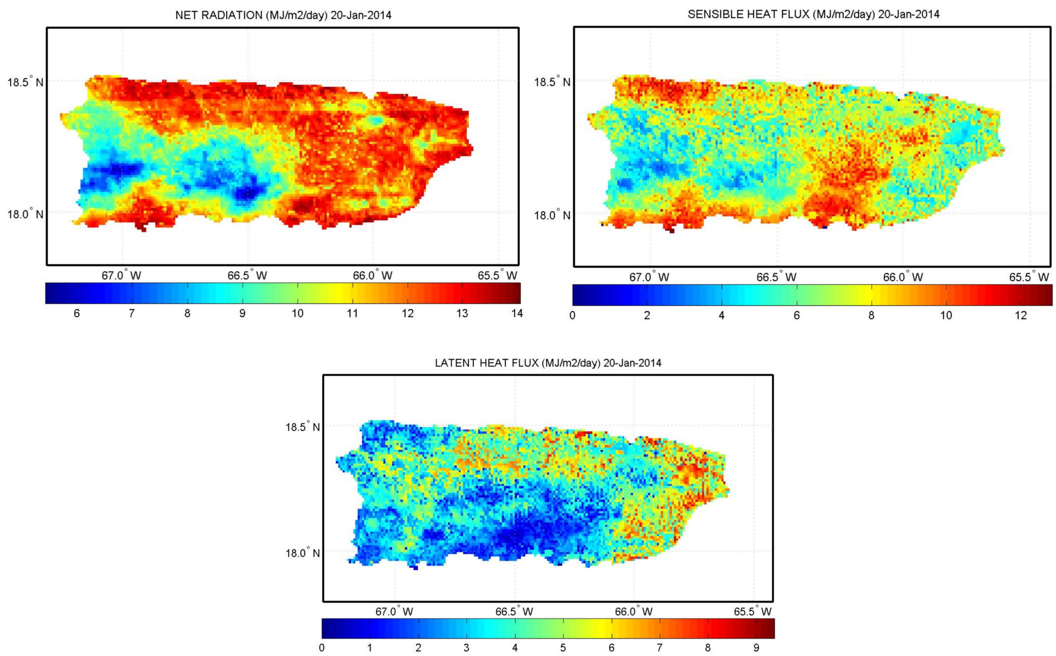

Figure 2. Daily energy balance components produced by GOES-PRWEB for January 20, 2014.

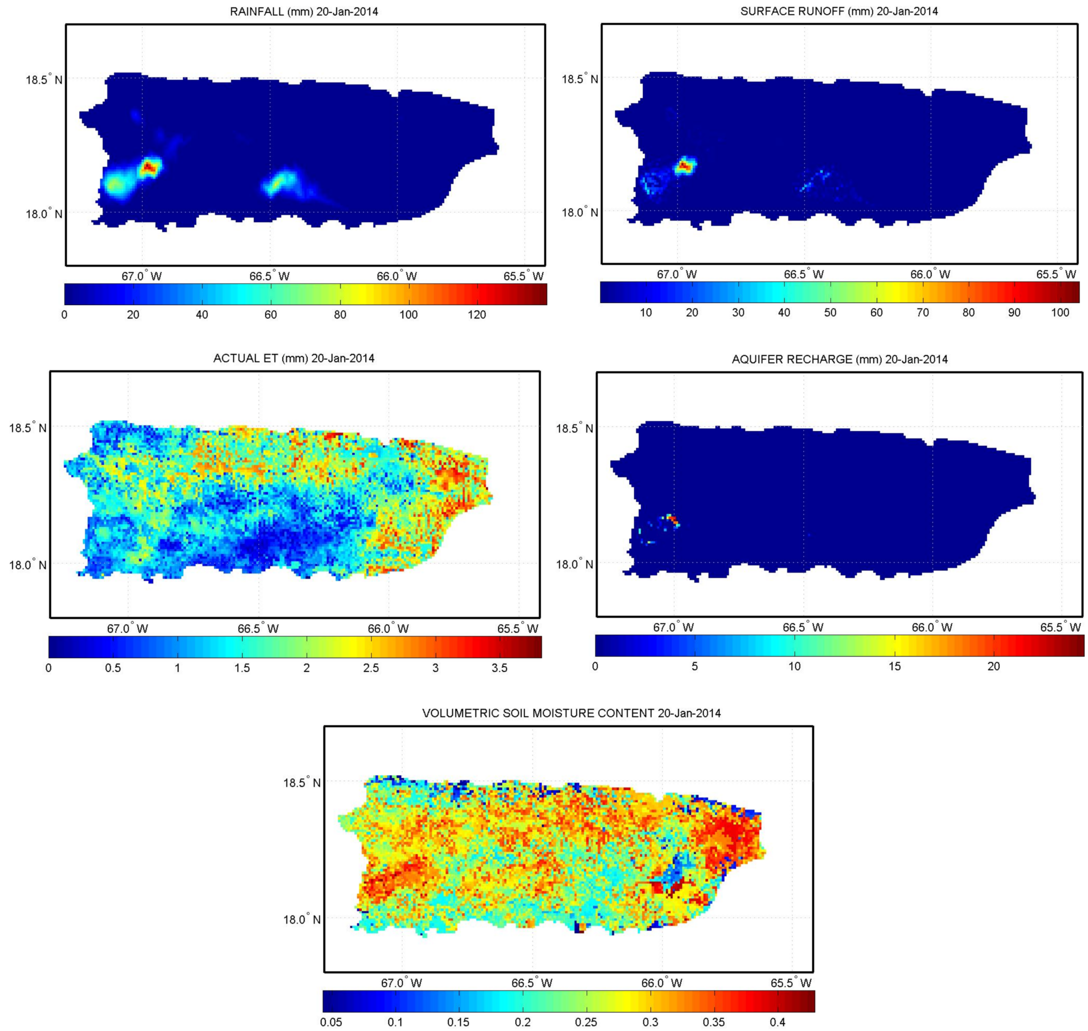

Figure 3. Daily water balance components produced by GOES-PRWEB for January 20, 2014.

Recent Research in Costa Rica

Conclusions and recommendations

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