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Impact of biases in gridded weather datasets on biomass estimates of short rotation woody cropping systems

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ABSTRACT

Short rotation woody crop (SRWC) systems continue to be investigated as energy crops for a range of energy products including liquid biofuels and electricity. To understand their market potential and economic viability, regional biomass yield and production estimates are used as primary inputs. Biomass is generally estimated using growth models which often utilize gridded weather datasets when implemented for regional simulations. With such models, the accuracy of weather data will affect the uncertainty of estimated biomass and subsequent bioenergy analyses. This study evaluates the biases in weather variables of commonly used high resolution gridded datasets including PRISM, Daymet, NARR, and NLDAS in comparison with observed weather at five flux tower stations. Further, impacts of inaccuracies in gridded data sources on biomass estimates of SRWC hybrid poplar was investigated at site and regional levels using a version of the 3-PG growth model modified to model production with multiple harvests through coppicing or periodic cutting of the trees with regrowth from the tree stump.

Results suggest that weather variables in all gridded datasets are characterized by some degree of bias leading to considerable bias in biomass estimates, in some cases up to 45%. PRISM and Daymet were shown to have lower uncertainty in most of the weather variables, likely due to their higher spatial resolution and higher dependency on station weather. Site level simulations indicate that relative to the reference biomass estimates based on actual weather measurements, NARR data yielded 4.1 Mg ha^{-1} y^{-1} higher biomass while NLDAS, Daymet, and PRISM resulted in 3.3, 1.2 and 0.3 Mg ha^{-1} y^{-1} lower biomass. Regional simulations suggest that total biomass varied substantially with gridded data sources ranging between 47.4 and 58.3 Tg on the croplands and rangelands in the region (Columbia Plateau), which subsequently led up to 23% variation in the estimate of poplar based jet fuel production from the SRWC resource. Therefore, findings of this study reinforce the need to account for uncertainties in biomass estimates introduced by biases in gridded weather when modeling bioenergy production.

1. Introduction

Biomass from short-rotation woody crops (SRWC) such as hybrid poplar (*Populus* spp.), willow (*Salix* spp.), eucalyptus (*Eucalyptus* spp.) has been investigated as a promising renewable feedstock resource for the production of bioenergy and other bio-based products (Hinchee et al., 2009). SRWC have many attributes that make them attractive for biomass cropping systems including their fast growth, coppicing ability for some species (i.e. their ability to resprout after harvest), ease of propagation, adaptability to various climate and soil conditions, and utility in helping to restore soil quality (Sims and Venturi, 2004; Rockwood et al., 2004; Hinchee et al., 2009). At present, these systems are mostly pre-commercial as energy crops, and there have been many regional-scale feasibility studies investigating the technical, economic, environmental and, social aspects associated with deploying SRWC systems at multiple scales (Dubuisson and Sintzoff, 1998; Hoffmann and Weih, 2005; Volk et al., 2006; Buchholz and Volk, 2011; Miao et al., 2012; Bandaru et al., 2015). The common primary inputs used in most of these studies are the estimates of potential biomass production. Biomass estimates are required to determine net energy potential under different management systems and technologies (Schmer et al., 2008; Bandaru et al., 2013), economic costs associated with biomass collection and supply to refineries (Downing and Graham, 1996; Hoogwijk et al., 2009), net economic benefits of feedstock production (Allen et al., 2013), cost competitiveness with current

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cropping systems (De La Torre Ugarte and Ray, 2000; McLaughlin and Adams Kszos, 2005; English et al., 2006; Egbendewe-Mondzozo et al., 2011), and carbon sequestration potential (Deal et al., 2014). Biomass yields are also used as key inputs in system optimization models to identify cost-effective biomass supply locations and to develop sustainable supply chains for the production of bioenergy and other products (Parker et al., 2010; Bandaru et al., 2015). In addition, regional simulated yields are often used to identify areas for more intensive study and planting of actual field trials.

Forest growth models or modifications of them are typically applied to determine potential regional SRWC biomass estimates under different management conditions (Deckmyn et al., 2004; Amichev et al., 2011; Tallis et al., 2013; Hart et al., 2015). These models use principles of plant growth and their interactions with weather, soil and management to predict biomass yields. For model implementation, various input variables (e.g. soil characteristics, plant parameters, weather variables) are required, among which weather factors have the most significant impact on model estimates. Weather factors influence various biophysical processes (e.g. transpiration, photosynthesis) that drive plant growth and development (Hoogenboom, 2000). Weather fluctuates substantially with time and space, and its effect on plant growth is generally non-linear. Therefore, errors in weather variables will have a large impact on model estimates that subsequently may lead to inaccurate results and conclusions and inappropriate decisions, such as investment decisions that depend on good understanding of potential biomass yields and other attributes (Stallings, 1961; Semenov and Porter, 1995; Tao et al., 2009; Van Wart et al., 2013). Therefore, the choice of a weather data source and its data quality are critical to obtain accurate biomass estimates to be used in other models.

Models can use either observed weather data collected at meteorological stations or gridded weather data, that is distributed weather estimates based on interpretations of weather measured elsewhere. When models operate at regional scale, gridded weather data sets are commonly used because they offer full spatial coverage of the region of interest with data for each grid cell, and there may be insufficient density of weather stations to represent adequate spatial weather patterns over large areas (Van Wart et al., 2013). Gridded weather datasets are generally produced using (1) interpolation techniques to interpolate observational weather data and topographic characteristics or (2) data modeling and assimilation techniques (Eum et al., 2014) that attempt to model changes in weather across a region based on local topographical, land cover, and other attributes. As grid-point associated weather values in gridded weather datasets are for the most part not observational data, there are uncertainties in these values, and the degree of uncertainty varies with the source of the weather data and the assimilation technique used to generate the gridded data. Thus, quantifying the uncertainties in gridded data sets compared to observational data is important to understand their impact on model yield and production estimates.

Given the significance of weather data quality on biomass estimates, this study was conducted with two specific objectives: (1) to evaluate weather data quality of four commonly used high resolution gridded weather datasets available for the U.S.: the NARR (North American Regional Reanalysis), NLDAS (North American Land Data Assimilation System), PRISM (Parameter-elevation Relationships on Independent Slopes Model), and Daymet and (2) to quantify the impact of uncertainty in weather variables on biomass yield estimates of SRWC hybrid poplar at specific site and regional levels. Hereafter for conciseness, we refer to gridded weather datasets as gridded data. In this study, hybrid poplar is chosen because it is a widely studied SRWC for biofuel production and a coppiced-based growth model (Hart et al., 2015) has already been developed to predict yields as part of a larger optimization modeling framework (Bandaru et al., 2015).

2. Materials and methods

We used observed weather data from five flux tower sites as reference data to assess the uncertainty in five weather variables of the various gridded data sets. Weather variables include (1) minimum air temperature (T_{min}) (2) maximum air temperature (T_{max}) (3) solar radiation (SR) (4) precipitation (Precip) and (5) dew point temperature (T_d). We simulated biomass estimates of hybrid poplar cultivated with a 3-year rotation period at flux tower site and regional levels using a modification of the Physiological Principles in Predicting Growth (3-PG) poplar model (Landsberg and Waring, 1997; Landsberg et al., 2003; Hart et al., 2015). Site-level simulations were carried out using gridded data and weather data at the flux tower sites, and the differences in the model estimates were used to determine relative uncertainty in the biomass yield estimates. Regional simulations were based on the gridded data only, and these estimates were used to determine differences in spatial patterns and total biomass estimates with use of the various gridded datasets.

2.1. Study region

Regional simulations were implemented over croplands and rangelands in the Columbia Plateau region that extends across the states of Washington, Oregon and Idaho covering 260,000 km^2 (Fig. 1). This region within the Pacific Northwest of the U.S. is renowned for diverse landscape features and major agricultural land use and is already under investigation for its potential in producing biofuels and other bio-based products. The elevation in the region ranges from 60 to 1500 m above sea level. Most of the region is characterized by a semi-arid climate as 57 percent of the region receives less than 380 mm annual precipitation (Vaccaro et al., 2015). Average annual precipitation varies with geographical location, ranging from 177 mm in the central part of the region to more than 1000 mm in the surrounding mountains (Vaccaro et al., 2015). The average annual precipitation of the entire region is 430 mm and the average annual temperature ranges from 4 to 14 °C (40–57 °F).

2.2. Weather databases

2.2.1. Observational data

We selected flux tower sites as opposed to weather stations because observations at weather stations are included as input to generate some of the gridded datasets (e.g. PRISM and Daymet) and therefore do not constitute as an independent source for comparison. Five flux tower sites were selected for reference data to evaluate and quantify the biases in gridded datasets. We chose sites that are situated on either grasslands or croplands, and have weather data for at least four years, and have all the weather variables required for model simulations. We discarded flux tower sites located on forest land due to perceived influences of forest cover on weather station data. The selected flux tower sites include (1) Audubon Research Ranch, AZ (2) Bondville, IL (3) Fort Peck, MT (4) Mead Rainfed, NE (5) Varia Ranch, CA. Details of the sites are listed in Table 1.

2.2.2. Gridded weather databases

There are a number of gridded datasets covering the U.S. However, most are characterized by coarse spatial resolution (>0.5°). In this study, we evaluated high resolution gridded data that have a spatial resolution less than 0.5° commonly used in terrestrial ecosystem modeling (Zhang et al., 2010; Bandaru et al., 2013; Hart et al., 2015). The details of the selected gridded datasets