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Modeling Coupled Climate and Urban Land Use Change in the Eastern United States

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Abstract

Urban land cover and associated impervious surface area (ISA) are expected to increase by as much as 50% over the next few decades across substantial portions of the coterminous U.S. In combination with urban expansion, changes in temperature and precipitation are expected to impact ecosystems through changes in productivity, disturbance and hydrological properties. In this study, we use land cover predictions from the Spatially Explicit Regional Growth Model (SERGoM) model through the year 2100 and an ensemble of climate projections (Bias Corrected and Downscaled WCRP CMIP3) for large watersheds of the eastern United States to explore the impacts of urbanization and climate change on hydrologic dynamics (runoff) and vegetation carbon uptake (gross productivity). We use the Terrestrial Observation and Prediction System (TOPS), an ecosystem modeling framework, to simulate the influence of these changes, as well as potential adaptation actions associated with land use. We describe the modeling approach, and results from initial modeling experiments to quantify the component and cumulative impacts of climate and land use changes forecast to occur in the region. We also describe our approach to characterizing the mitigation potential of various best management practices for land use planning, such as urban afforestation and replacement of asphalt with permeable surfaces.

Approach

Simulations to evaluate impacts of climate and land use change on runoff and gross primary productivity (GPP) are conducted using BIOME-BGC (Thornton et al., 2002), which been integrated within TOPS (Nemani et al., 2007) as a component model. BIOME-BGC requires as inputs spatially continuous data layers to describe the land cover, soil texture and depth, daily meteorology, and elevation across the land surface. BIOME-BGC can also use satellite-derived estimates of leaf area index (LAI) to parameterize equations for photosynthesis and plant growth. The modeling experiments are being conducted using the NASA Earth Exchange (see Poster # IN53A-1161).

We use the following inputs to parameterize the model for the baseline and forecast scenarios for two different regions being studied: the Chesapeake Bay & Delaware River watersheds, and the eastern U.S.

Input Parameter	Chesapeake / Delaware (250m)	Eastern United States (1km)
Impervious surface area	SERGoM (Theobald et al., 2009)	
Climate (baseline run)	TOPS-SOGS Weather Surfaces	
Climate (forecast)	WCRP CMIP3 (Maurer et al., 2007) GFDL CM2.0, NCAR CCSM3.0, GISS-ER Scenarios A1B, A2, B1	
Elevation	National Elevation Dataset (resampled)	
Leaf Area Index (baseline run)	MODIS MOD13Q1 NDVI and MOD15A2 LAI algorithm	MODIS MOD15A2 LAI (Myneni et al., 2000)
Leaf Area Index (forecast)	MODIS MOD15A2 LAI Climatology	Simulated by BIOME-BGC
Soils	U.S. STATSGO2 database	
Land Cover	NLCD2001 (Homer et al., 2004) Cross-walked to IGBP	MODIS MOD12Q1 Land cover (Friedl et al., 2002)

Table 1. Data sources used for model inputs

Approach (cont'd.)

Land cover change

Housing density forecasts from the SERGoM scenarios (Theobald et al., 2009) are used to estimate the ISA for the U.S. at a native resolution of 100m, and resampled to 1km at a decadal time-step (Fig 1). BIOME-BGC does not directly utilized ISA as an input parameter, however, ISA directly reduce soil water holding capacity and has been shown to increase runoff (e.g., Carlson 2004;Rose & Peters 2001), and thus we use ISA (% of pixel) to scale the soil depth (D) as $D_t = (1 – ISA) * D_0$

For the eastern U.S., the baseline land cover is derived from the MODIS MOD12Q2 1km land cover product, and the baseline ISA is derived from the National Land Cover Database (NLCD) 2001 ISA data. For runs conducted for the Chesapeake watershed, we used the NLCD 2001 30m dataset, resampled to a spatial resolution of 250m using a majority vote algorithm.

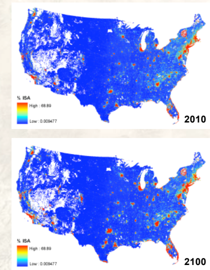

Fig 1: SERGoM ISA forecast, 2010 & 2100

Climate

For the baseline runs (2001-2010), we use the Surface Observation and Gridding System (Jolly et al., 2005), a component of TOPS, to interpolate surface observations to a 1km continuous grid. For the grids for the Chesapeake region, we applied algorithms based on DAYMET that follow Thornton et al. (1997) to produce the required meteorological inputs for BIOME-BGC. Future climate scenarios are based on downscaled WCRP CMIP3 scenarios (Maurer et al., 2007). We are using three models (GFDL CM2.0, GISS-ER, CCSM3.0) and three scenarios for each model (A1B, A2, B1), for a total of nine scenarios. The corresponding SERGoM scenario (A1, A2, or B1) is used for each run (Fig 2).

Streamflow

Daily streamflow data from 2000-2010 is retrieved for stations within each major watershed analyzed to assess the accuracy of the modeled runoff volumes from TOPS. For the Chesapeake simulations, data from the UGSS Streamflow Gauge at Trenton NJ (ID# 01463500, Latitude 40°13'18", Longitude 74°46'41) were retrieved from the USGS National Water Information System (http://waterdata.usgs.gov/nwis).

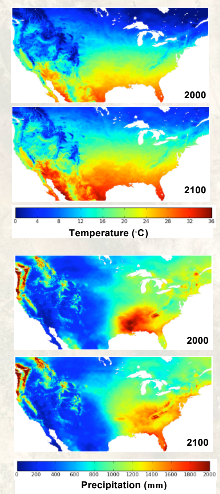

Fig 2: Forecasted changes in temperature and precipitation from 2000 to 2100 from the GFDL CM2.0 A1B scenario.

Mitigation measures

As part of the modeling experiment, we are assessing the potential for various best management practices (BMPs) to mitigate the impacts of climate and land use change. The potential for a combination for BMPs including green roofs, permeable concrete, and smart growth to mitigate land use change impacts will be evaluated through two additional ISA scenarios which represent these BMPs through modifications to the fractional ISA and land cover. For example, green roofs are modeled as grassland land cover types, and permeable concrete and smart growth are represented as reductions in ISA relative to the SERGoM forecasts. In addition, the potential for increases in urban forest cover to mitigate potential reductions in GPP is modeled through increases in LAI, derived from relationships between the MODIS Vegetation Continuous Fields (Hansen et al., 2007) and the average annual LAI, and are used to scale the LAI climatology for urban regions for the two BMP scenarios, which represent moderate and aggressive mitigation efforts.

Initial Results

While current model simulations for the U.S. are ongoing, a series of initial simulations have been completed to evaluate the impacts of land use change on the Chesapeake Bay and Delaware River watersheds (216,800 km²) in the eastern U.S. for the period from 2000-2030 (Goetz et al., 2009). These initial simulations predicted a15% increase in runoff per storm event, and an overall increase in cumulative annual runoff of 1%, or 1.5 billion m3–H2O/yr (Fig 4). Projected decreases in GPP in this modeling experiment were estimated at 14 million kg-C per year, or approximately 5% of the total annual estimated GPP of 290 million kg-C for the region (Fig 5).

Observed vs predicted outflow

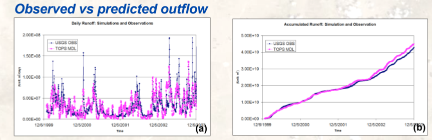

Fig 3: Comparison of predicted daily (a) and cumulative (b) runoff from TOPS against observed runoff from the USGS stream gauge at Trenton for 2000-2003.

Forecasted outflow

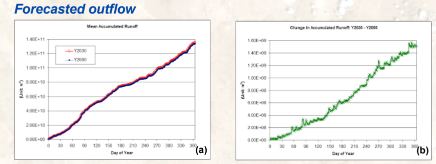

Fig 4: Forecasted average cumulative runoff over the simulation periods. Total cumulative runoff for both the baseline (2000) and forecast (2030) scenarios is shown in (a), and the difference between the baseline and forecast scenarios is shown in (b).

Forecasted GPP

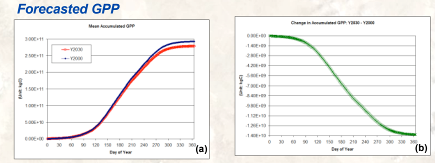

Fig 5: Forecasted average cumulative GPP over the simulation periods. Average cumulative GPP for the study region for both the baseline (2000) and forecast (2030) scenarios is shown in (a), and the difference between the baseline and forecast scenarios is shown in (b). Units are expressed in kg of carbon.

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