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Estimation of biogenic emissions with satellite-derived land use and land cover data for air quality modeling of Houston-Galveston ozone nonattainment area

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Abstract

The Houston-Galveston Area (HGA) is one of the most severe ozone non-attainment regions in the US. To study the effectiveness of controlling anthropogenic emissions to mitigate regional ozone nonattainment problems, it is necessary to utilize adequate datasets describing the environmental conditions that influence the photochemical reactivity of the ambient atmosphere. Compared to the anthropogenic emissions from point and mobile sources, there are large uncertainties in the locations and amounts of biogenic emissions. For regional air quality modeling applications, biogenic emissions are not directly measured but are usually estimated with meteorological data such as photo-synthetically active solar radiation, surface temperature, land type, and vegetation database. In this paper, we characterize these meteorological input parameters and two different land use land cover datasets available for HGA: the conventional biogenic vegetation/land use data and satellite-derived high-resolution land cover data. We describe the procedures used for the estimation of biogenic emissions with the satellite derived land cover data and leaf mass density information. Air quality model simulations were performed using both the original and the new biogenic emissions estimates. The results showed that there were considerable uncertainties in biogenic emissions inputs. Subsequently, ozone predictions were affected up to 10 ppb, but the magnitudes and locations of peak ozone varied each day depending on the upwind or downwind positions of the biogenic emission sources relative to the anthropogenic NO_x and VOC sources. Although the assessment had limitations such as heterogeneity in the spatial resolutions, the study highlighted the significance of biogenic emissions uncertainty on air quality predictions. However, the study did not allow extrapolation of the directional changes in air quality corresponding to the changes in LULC because the two datasets were based on vastly different LULC category definitions and uncertainties in the vegetation distributions.

Keywords: Biogenic emissions; Land use/land cover; Satellite data; Air quality; Ozone; Leaf mass density; Photosynthetically active solar radiation; TexAQS experiment

1. Introduction

Development of reliable land use (LU) and land cover (LC) data is a key activity of environmental management. The LULC data is a critical input for characterizing land surface processes in meteorological modeling and in estimating the influence of trees on urban and regional air quality. Different distributions of LULC can influence meteorological conditions such as air temperature, moisture, and the height of the planetary boundary layer in which pollutants are dispersed and transformed. Changes in land

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use and land cover in a rapidly developing metropolitan area can modify radiative conditions and thus result in regional climate changes. For example, LULC modification can exacerbate the urban heat island (UHI) effects in a metropolitan area like Houston-Galveston when the vegetation cover is replaced with buildings and pavement. Also, the extended impervious surface may enhance the run off of rainfall and increase the sensible heat flux and air temperature, thus modifying the turbulent mixing conditions in urban areas (Oke, 1987; Taha et al., 2000). There are a few attempts to mitigate such problems by introducing more plants in the urban environment, paving with light color and porous materials, and installing reflective roofing materials.

Although reducing the effects of the UHI can be beneficial, for example by reducing summer air conditioning costs, there is a controversy whether these measures will always mitigate local ozone problems. Changes in the land use and land cover will induce further changes in the amount vegetation can eliminate pollutants from the air through dry deposition. Deciduous trees are well known to generate a significant amount of photochemically sensitive biogenic emissions of volatile organic compounds (VOCs), carbon monoxide (CO) and nitrogen monoxide (NO), as well as monoterpenes which are precursors of secondary organic aerosols (SOAs). The rates of the biogenic emissions are heavily dependent on the environmental factors that affect tree and vegetation physiology, such as ambient temperature, moisture, and in particular the photosynthetically active solar radiation (PASR) component. For example, lower temperature could have beneficial effects by reducing the amount of such ozone precursor emissions. Refer to Guenther et al. (1993, 1994) and Pierce et al., (1998) for the details. However, decreased temperatures could also produce lower mixing heights in which precursors and secondary air pollutants can disperse, thus increasing ozone concentrations. Therefore, there is a need to perform a thorough assessment of these issues by using advanced computer modeling to evaluate whether an expanded tree planting program would mitigate ozone problems in an urban area like the Houston-Galveston Area (HGA).

An LULC dataset is an essential input for the estimation of regional biogenic emissions. The higher the spatial resolution and the larger the numbers of plant species available, the better the estimations are that can be expected. Texas Commission on Environmental Quality (TCEQ, 2002) utilizes a high quality LULC dataset (Wiedenmyer et al., 2001) for biogenic emission estimates. However, there are a few areas of uncertainties with the LULC dataset because it is a compilation of various data sources over many years of time span and has many components that depend on the county-based surrogate information (for example population, socio-economic databases, crop yields for each count, etc.), and therefore, some spatial distributions are limited by county boundaries. Recently, the Texas Forest Service (TFS), with the support of TCEQ, has compiled a new high-resolution LULC dataset for the eight counties surrounding the HGA to characterize regional changes in the vegetation and tree species. The updated map of LULC was produced using satellite imagery and ancillary datasets. A supervised classification process using image processing software was employed to define 8 land cover classes and 15 land use classes (GEM, 2003).

The new set of vegetation and LULC data, when compared with the TCEQ dataset, provides an opportunity to evaluate the impact of LULC data uncertainties on the biogenic emission estimates and eventually on air quality simulations. The present research examines the effects of LULC changes on the local biogenic emission estimates without considering the indirect effects on the meteorological conditions. In this study two different biogenic emission datasets are used in air quality simulations to quantify their effects on the predicted ozone concentrations in the HGA.

2. Materials for analysis

The study area for land use and land cover is the Houston-Galveston area including the surrounding counties of Brazoria, Chambers, Fort Bend, Galveston, Harris, Liberty, Montgomery, and Waller in South East Texas, as shown in Fig. 1. The period of modeling analysis is August 22–September 1, 2000, a part of the Texas Air Quality Study 2000 (TexAQS 2000).

2.1. Land cover and land use data

2.1.1. TCEQ biogenic landuse data set

For the HGA State Implementation Plan (SIP), TCEQ supported development of a dataset of land use and vegetation for the state of Texas and the surrounding states. Compared to other parts of Texas and the US, the LULC database available for Eastern Texas has been updated relatively recently (Wiedenmyer et al., 2001). It is a composite land use database that includes a mapping of ground cover, vegetation species, and leaf mass densities for the state of Texas. Land use and vegetation were divided into over 600 classifications at approximately 1 km spatial resolution (Fig. 2). Some field surveys were performed to estimate leaf biomass densities of certain tree species. The dataset contains more detailed urban LULC classifications. When no recent data were available, the USGS-LULC database at 1 km resolution (http://www.lib.ncsu.edu/stacks/gis/lulc.html) was applied to provide spatial distribution of the urban land use types. In addition to the municipal, state, and Federal government land use, land cover, and vegetation data at resolutions from 30 m to 1 km, county-based agricultural LULC data were incorporated as well. Although this LULC database has a reference year of