Utilization of Satellite-derived High Resolution Land Use/Land Cover Data for the Meteorological, Emissions, and Air Quality Modeling

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1. INTRODUCTION

Houston-Galveston area (HGA) is one of the most severe ozone non-attainment regions in the US. A primary goal of this research is to study how the changes in the land use (LU) and land cover (LC) impact on the air quality in the HGA. Recently, the Texas Forest Service (TFS), with the support of Texas Commission on Environmental Quality (TCEQ), has compiled a high-resolution (~30m) LU/LC dataset for the eight counties surrounding the HGA to characterize regional changes in the vegetation and tree species. The updated map of LU/LC was produced using satellite imagery and ancillary datasets. A supervised classification process using image processing software was employed to define the 8 land cover classes and 15 land use classes.

Changes in the LU/LC not only affect physical characteristics involved in surface flux and radiative energy exchanges, but also influence the amount of biogenic emissions produced by the vegetation. Both the meteorological and emissions input data are keys in determining the air quality in a region. For the biogenic emissions estimates, a 1-km biogenic LU/LC dataset, which is partially based on the USGS data, was originally utilized. The higher the spatial resolution of the data and the larger the numbers of plant species available, the better the estimations that can be expected.

Combined with the field plot information, satellite estimates of tree cover (stratified by the land use type specified in the new dataset), and detailed leaf mass density (LMD) data for HGA developed by the US Forest Service, we estimated changes in the biogenic emissions. The large changes in the vegetation cover would result in significant changes in biogenic emissions.

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In this paper we present effects of utilizing the high resolution LU/LC data on the meteorological simulation results, biogenic emissions estimates, and finally simulation results of air quality with the new meteorological and emissions inputs to study the overall impacts on the assessment of photochemical modeling of high ozone events in the Houston-Galveston metropolitan area.

2. BACKGROUND

Urbanization of mega-cities like Houston occurs with significant change in the land-use and land-cover characteristics such as clearing of existing trees and vegetations in the outskirts of the urban areas, and added buildings, roads, and other structures. These changes may intensify the urban heat island (UHI) effects in the region. New tree planting programs such as Houston Green project has the stated goal of improving the livability of the Houston urban areas, but may also produce other beneficial effects, such as reduced summer air conditioning costs in cities.

TFS and TCEQ are interested in studying impacts of the modified UHI effects on the Houston air quality. As volatile organic carbon (VOC) emissions from certain tree species are reduced at low temperatures, and some photochemical reactions are dependent on air temperature and on VOC and NO_x emissions, some argue that lower air temperature would have the additional beneficial effect of reduced ozone formation in and around the city. Decreased temperatures, however, could produce lower mixing heights in which precursors and secondary air pollutants can disperse, thus increasing ozone concentrations. A need thus exists to develop a thorough assessment of these issues by using advanced computer modeling to evaluate whether an expanded tree planting program would help to reduce ozone production in HGA and help to contribute to achievement of the ozone mitigation goals in the TCEQ's State Implementation Plan

(SIP) for improving air quality in the region. In this study, we divided our research into four tasks with focuses on: (a) surface characterization parameter-development by use of the new TFS land-use/ vegetation data base, (b) MM5 simulations that use the new surface input parameters, (c) preparation of biogenic emissions data by use of the new land-use/vegetation dataset, and (d) air quality simulations to quantify the effects of these different meteorological input and biogenic emissions data on regional ozone concentrations.

To simulate air quality and develop emission control plans to achieve ozone attainment within the specified SIP time-frame of TCEQ, we have first performed research on the following three focus areas: (1) develop meteorological data with the new LU/LC data by use of the MM5 mesoscale model, (2) estimate biogenic emissions data with the new LU/LC and vegetation data using the EPS2 emissions processor, and (3) evaluate the combined effects of the modified surface temperature and biogenic emissions on air quality. Byun et al. (2003) describes these data processing steps.

3. SATELLITE-DERIVED HIGH RESOLUTION LAND USE AND LAND COVER DATA

For the HGA SIP modeling purpose, TCEQ is utilizing a specially compiled dataset for land use and vegetation information for the state of Texas and the surrounding states. Compared to other parts of Texas and US, the LU/LC database available for Eastern Texas is updated relatively recently. 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 (Weidinmyer, et al., 2001). Land use and vegetation types were divided into over 600 classifications at approximately 1 km spatial resolution. Some field surveys were performed to estimate leaf biomass densities of certain tree species. Special emphasis was put in to generate more detailed urban LU/LC classifications. When no recent data were available, the USGS LU/LC database at 1-km resolution 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 LU/LC data were incorporated as well.

The year 2000 land cover and land use GIS shape file dataset from Texas Forest Service (GEM, 2003) covers the eight county areas surrounding Houston (see Figure 1) and consists of 8 land cover classes and 15 land use classes. An updated map of land use and land cover type conditions within the eight counties surrounding Houston, Texas was produced using satellite imagery and ancillary data sets (Figure 2).

Impervious surfaces were distinguished as roads, parking lots and buildings dependent upon the ability of the satellite's 30meter pixel resolution to identify the features. Land uses were mapped according to the following classes: Forest range agriculture urban/developed. The separation between urban and non-urban areas was identified by year 2000 census data. Land use conditions within the urban areas were further classified as residential, commercial, industrial, transportation corridors, and parks. The separation between urban and non-urban areas was identified by year 2000 census data. Land use conditions within the urban areas were further classified as residential, commercial, industrial, transportation corridors, and parks. Surface properties including albedo, surface roughness, emissivity and thermal inertia were mapped through direct measurement when possible and, otherwise, through the use of look-up-tables that assign a value according to cover type. Several data sources were utilized to enhance feature identification and improve the classification process. The data sources included LANDSAT satellite imagery, digital aerial photography, aerial LIDAR data, USGS elevation data, a variety of vector based GIS data, and extensive ground-truth information obtained from more than three hundred field plots.

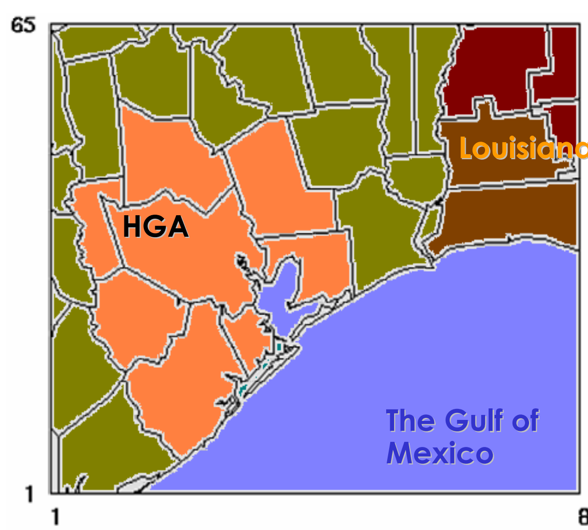

Figure 1. Houston eight county area (in orange color), where the LANDSAT-derived LU/LC data are available.

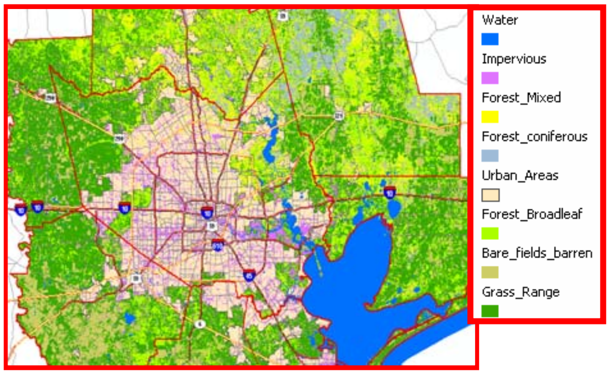

Figure 2. A composite map of land cover and land use data obtained from the LANDSAT.

The multi-resolution and multi-temporal data sets were correlated to develop unique class parameters for optimal recognition of land use and cover type features. The higher resolution data sets were used to perform a sub-pixel analysis of the LANDSAT imagery over selected field plot locations in order to produce spectral signatures for the associated cover types. The spectral signatures were then extrapolated across the entire study area to assign a land cover type to each picture element (pixel) in the satellite imagery using the Spectral Angle Mapper algorithm within the ENVI software package by Research Systems, Inc.

The Land Use classification was conducted following the cover type analysis by means of a manual interpretation of all the data, including the cover type classification, the LANDSAT imagery and the ancillary data sets. On screen digitizing of land use class boundaries was performed for the urban sub-classes of residential, commercial, industrial and parks. The total volume of data for the project exceeded a terabyte of information. Data sets in raster format included LANDSAT 7 satellite data, aerial photography, LIDAR data and USGS elevation data. Data sets in vector format included field plot data, county boundaries, Census 2000 urban boundaries, transportation routes, hydrology, wetlands, parks (City, County, State and National), and grid domains for air quality modeling activities. It should be noted that the new LANDSAT based LULC may represent nether the identical reference year nor changes in the forest cover in Houston because the original TCEQ BIO-LULC data is a composite of several different data sets completed during different years. The differences we see between the two may be due to things other than the changes in forest density, though that is probably one of the major factors.

4. METEOROLOGICAL SIMULATIONS

We have performed meteorological simulations with MM5 using a recent NOAH land-surface model (N:National Center for Environmental Prediction; O: Oregon State University; A: Air Force; H: Hydrological Research Lab.) (Ek et al., 2001) to see if use of the LANDSAT-based data would improve meteorological model output. Our 4-km grid meteorological simulations were compared with the base MM5 simulations from TCEQ and hourly meteorological observations at surface sites for the period of August 22 - September 1, 2000, a part of TexAQS 2000 period (Cheng et al., 2003).

The MM5/NOAH codes were modified to accommodate the new LU/LC categories in addition to the original USGS 25 LU/LC categories. Utilization of the new LU/LC in the MM5 simulation with the NOAH land-surface model resulted in less scatters in the temperature predictions compared with the surface observations than the simulation with the original USGS LU/LC data (see Figures 4 and 5).

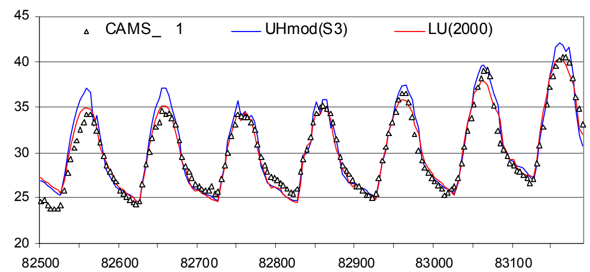

Figure 4. Example time series of surface temperature at CAMS site 1 in Houston predicted by MM5 with the original USGS LU/LC (UHmod, S3) and the high-resolution LANDSAT LU/LC (LU2000).

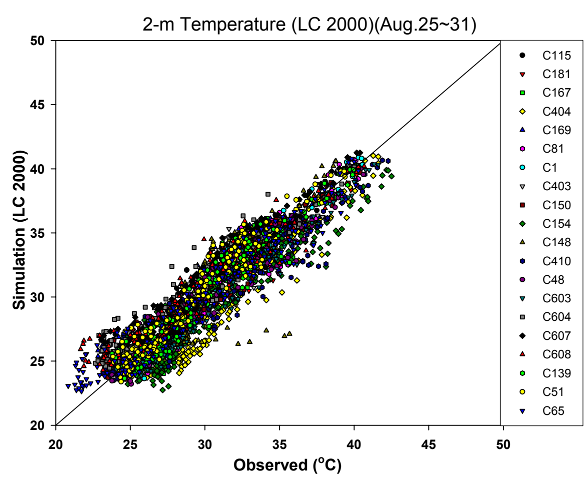

Figure 5. Scatter plot of the 2-m air temperature simulated with the high-resolution LANDSAT LU/LC data compared with the CAMS site measurements.

5. ESTIMATION OF BIOGENIC EMISSIONS

GloBEIS3 (Guenther et al., 2000; Yarwood, 2002) was used here to process biogenic emissions for the Houston-Galveston air quality modeling. GloBEIS3 requires land use and land cover and vegetation data for the estimation of biogenic emissions. One of the main purposes of this study is to compare GloBEIS3 results with the Texas biogenic LU/LC data and the LANDSAT based LU/LC data. To isolate the impact of the new LU/LC data, we utilized the observed temperature and GOES-derived radiation fields as described in Byun et al. (2004). Combining the new LANDSAT based LU/LC data with the leaf mass density data from US Forest Service (Nowak, 2004; personal communication) we have estimated biogenic emissions with the composite LU/LC database in ArcGIS shape file format for the 8-county area and the vegetation data.

The field plot information (350 plots) was combined with the satellite estimates of tree cover plots stratified by the land use type to estimate the leaf biomass by species type in each stratum. Instead of the existing LC codes in GloBEIS3, new LC description table describing the detailed lead mass density (LMD) for HGA developed by David Nowak was preliminarily used to link land cover classes with the new LC codes in GloBEIS3. Figure 6 shows steps used to estimate new biogenic emissions with the GloBEIS3 biogenic emissions utilizing the TFS-LULC and LMD data for HGA.

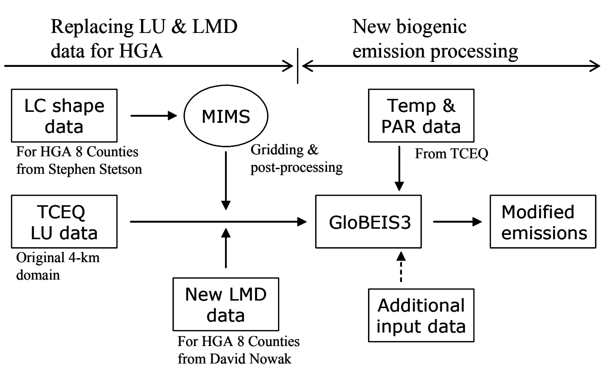

Figure 6. Procedures for the biogenic emission estimation utilizing new land use (LU), land cover (LC), and leaf mass density (LMD) data for the Houston-Galveston Area (HGA). MIMS stands for a GIS-shape file processor supported by U.S. EPA.

Isoprene emissions are mostly biogenic origin, therefore, differences shown here would affect ozone concentrations over the downwind areas of the high isoprene emissions areas (Figure 7). On the other hand, the contributions from the biogenic emissions for NO and CO are relative small (~5% and 8% of the domain totals) compared to their anthropogenic counterparts, such as mobile, area, and point sources. Therefore, it is expected that the changes in the biogenic NO and CO emissions would have negligible impact on air quality simulation results.

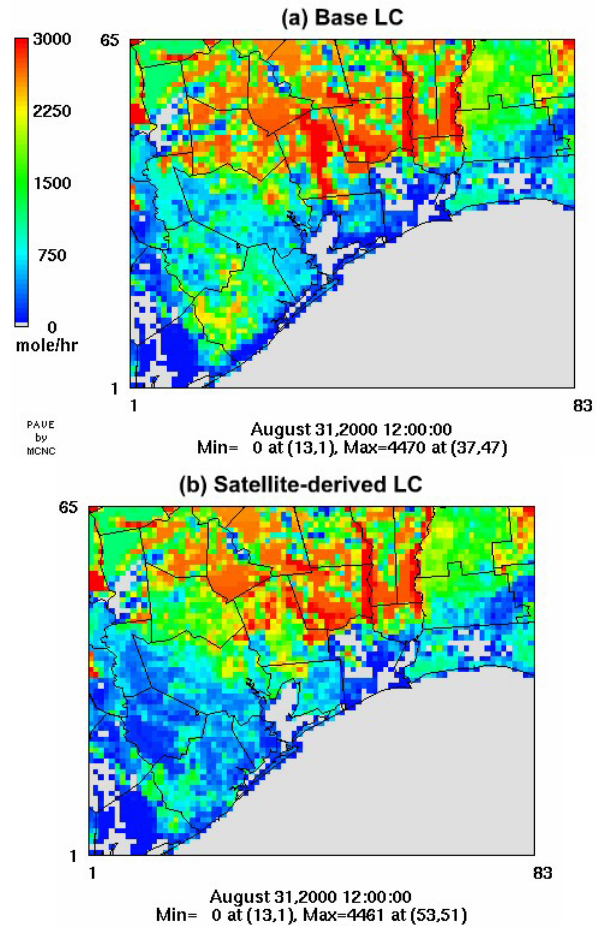

Figure 7. Spatial distribution of biogenic isoprene emissions estimated using (a) TCEQ biogenic LU/LC and (b) high-resolution LANDSAT LU/LC.

The areas with the most decreased isoprene emissions are located inside Liberty County, followed by Montgomery County. This is where the “Bottom Oaks” are located in the BIO-LULC database. It is suspected that the difference at this area may be due to the in-sufficient tree survey details available to match with the Satellite LU/LC classification (Mark Estes, 2004; personal communication). Most of the areas show decreased emission rates, but we can find a few spots at which isoprene emissions increased with the high-resolution LULC data, especially in Chambers County. No large changes in Harris County and around the Ship Channel area are observed. Figure 8 demonstrates effects of temperature changes on the isoprene emissions. As long as the air temperatures are below the wilting point, the higher air temperature results in the higher isoprene emissions.

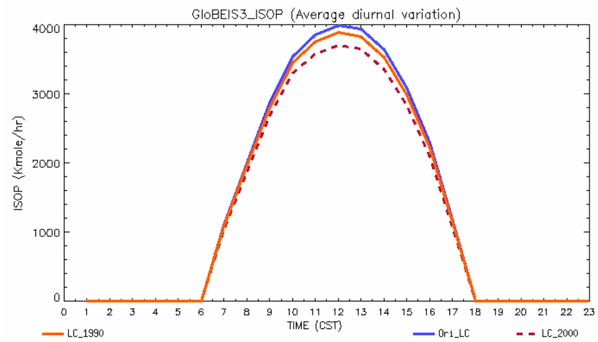

Figure 8. A comparison of time series of biogenic isoprene emissions among four different meteorological and land cover scenarios. The LANDSAT 2000 LC data (LC_2000) with lower temperatures estimates lower isoprene emissions than the original (Org_LC) and LANDSAT 1990 LC data with higher temperatures.

6. OZONE PREDICTIONS

<u>Effects of different biogenc emissions due to changes in LU/LC on air quality</u>

As described above, TCEQ has utilized the BIO-LU/LC database with reference year of 2000, although the representative years of the different data sources vary widely and in some cases uncertain. Byun et al. (2004) compared biogenic emission estimates from the TCEQ biogenic LU/LC and the LANDSAT-derived LU/LC datasets and their effects on the predicted ozone concentrations in the HGA by the CAMx air quality model. The results showed that the TFS LANDSAT data resulted in higher amount of biogenic NO emissions, lower isoprene and CO emissions than those from the TCEQ's original LU/LC data.

Because of the contributions of NO and CO emissions to the anthropogenic counterparts are relatively small, most of the differences in the air quality were resulted from the differences in the isoprene emissions amount. There were considerable differences in biogenic isoprene emissions and subsequently the ozone predictions were affected up to 10 ppb, but the magnitudes varied each day depending on the upwind or downwind positions of the biogenic emission sources relative to the anthropogenic NOx and VOC sources. Although the assessment had limitations due to the heterogeneity in the spatial resolution, the study highlighted the importance of biogenic emissions uncertainty on air quality predictions. However, the study did not allow extrapolation of the directional changes in air quality due to the changes in the LU/LC data from this study because of the vastly different LU/LC category definitions and uncertainties in the vegetation distributions in the two datasets.

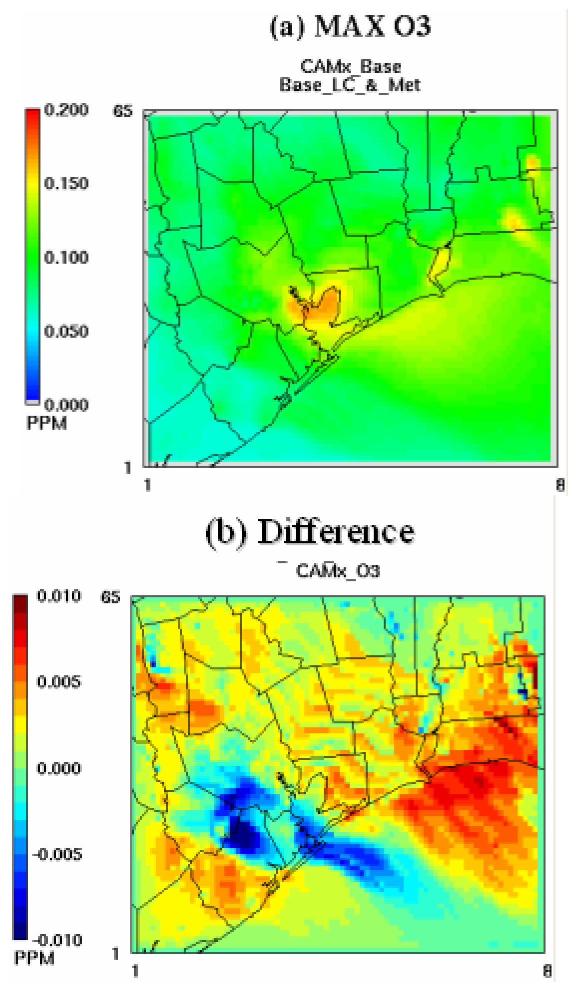

Figure 9. (a) Simulated maximum ozone with original LU data for August 31, and (b) difference in ozone maximum caused by the overall impact of using the high resolution LU/LC data.

<u>Overall Effects of LU/LC Change on Air Quality</u>

Differences in biogenic emissions can be caused by either changes in land use/land cover data or changes in the canopy temperature and/or both. Since this study needs to account for the changes in temperature corresponding to the changes in LC data would present as well, we focused our research on not only to identify which factors are predominant, but also to assess their overall impacts on the estimations of biogenic emissions, in particular, the isoprene emissions. It is suspected that changes in biogenic emissions are more related to land cover data rather than temperature (approximately 5:1 ~ 7:1) when the temperature differences ranged between -5 to 5 K. It is believed that the reason averaged diurnal variation of isoprene emissions present substantial difference for two temperature data is due to considerable difference in the estimation on August 22, 2000 when the MM5 greatly overestimated the temperature over the domain by more than 5 K.

To evaluate overall impacts of land cover changes on temperatures and ozone concentrations, discrete sets of LC and temperature data using LC2000 and LC1990 were compared. MM5 simulations using LC2000 predict lower air temperatures over the HGA eight counties by 2 to 3 K except for August 23. Along with lower isoprene emissions, CAMx simulations present lower ozone concentrations over and downwind areas of the HGA eight counties. Both lower isoprene emissions and lower air temperature with LC2000 resulted in slightly lower ozone concentrations than those only accounting for the changes in the land cover. It was found that, in general, daily maximum ozone concentrations increased across the domain as ambient temperatures increased. However, time series comparisons made at CAMS and other super sites showed consistent results that changes in ozone concentrations due to different ambient temperatures were not as important as those due to the land cover changes.

7. SUMMARY

Comparative model simulations were performed with several different LU/LC datasets. Meteorological modeling showed that the larger the vegetation area, the lower the air temperature. The air quality model sensitivity modeling resulted that the higher the air temperature the higher the ozone concentrations (Figure 9). The LU/LC changes not only modify the meteorological conditions, but also affect the biogenic emissions in the HGA atmosphere. The preliminary analysis results indicate that there are obvious benefits of greening the Houston-Galveston metropolitan area, such as lowering air temperature and thus the reducing the photochemical production of ozone when the increased vegetation covers are not contributing to the increase in the highly reactive biogenic ozone precursor emissions. This study demonstrates reduction of urban heat island effects by selectively planting more tree species that produce less isoprene emissions and increasing other vegetation area in the HGA has beneficial effects on improving ozone problems.

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