11.1 MODELING EFFECTS OF LAND USE LAND COVER CHANGES ON METEOROLOGY AND AIR QUALITY IN HOUSTON, TEXAS, OVER THE TWO DECADES

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1. INTRODUCTION

Recently, the Texas Forest Service (TFS), with the support of Texas Commission on Environmental Quality (TCEQ), has compiled a new high-resolution land use and land cover (LULC) dataset for the eight counties surrounding HGA (Houston-Galveston Area) to characterize regional changes in vegetation and tree species. The updated map of LULC was produced using LANDSAT satellite imagery and ancillary datasets for the base year 2000. A supervised classification process that uses an image processing software was employed to define the 8 land cover (LC) classes and 15 land use (LU) classes (GEM, 2003). The dataset was firstly used for meteorological, emissions, and air quality sensitivity model simulations to study the effects of (1) land use and land cover modification on the urban heat island development, (2) on biogenic emissions estimates, and (3) finally on the air quality in the HGA (Byun et al, 2004; Byun et al, 2005).

The LANDSAT pictures used for the processing were taken around October, 2000. After reviewing the details of the LULC data, it was suspected that the barren class shown in the picture might represent the agricultural land after harvesting but and before replanting and seeding. To resolve problems inherent with the LULC data such as the misinterpretation of land use types due to the time of the LANDSAT pictures, the land cover data were revised based on the land use data to better simulate the meteorological responses to land-surface interactions.

On the other hand, in order to predict air quality in correspondence to the LULC changes in future year, it was required to process biogenic emissions and to prepare input to meteorological model for the modified case. For the purpose, the 1992 National Land Cover Data (NLCD) was incorporated to provide a reasonable LULC change scenario for 2010 by linearly interpolating the trend from the past, through the present, and to the future.

For the biogenic emissions and meteorological simulations, the LULC data was also backwardly projected to have a comparable set of LULC data for 1992, 2000, and 2010 because the NLCD 1992 data utilized a very different set of LULC categories, which is not compatible with the MM5 mesoscale model.

The goal of this study was to examine how the changes in the land use and land cover impact on the air quality in the Houston-Galveston Area (HGA). We utilized these three sets of LULC data to study the overall impacts of the LULC changes on air temperature, biogenic emissions, and air quality. First, we simulated meteorological conditions using a modified MM5 with comprehensive NOAH land surface model for the TexAQS 2000 air quality episode (August 22nd-September 1st) to study effects of LULC change on the meteorology. The simulated canopy and air temperatures were then used to estimate biogenic emissions and to perform air quality simulations.

2. PROCESSING LAND COVER AND LAND USE DATA

2.1 TFS LULC data for year 2000

The Texas Forest Service (TFS) has produced a high-resolution (~30 m) land cover and land use dataset from LANDSAT multi-spectral pictures taken in September 2000 for the purpose of managing the urban forest in HGA. The high-resolution land use and land cover dataset is available for the Houston-Galveston area including the surrounding counties of Brazoria, Chambers, Fort Bend, Galveston, Harris, Liberty, Montgomery, and Waller in South East Texas (See Figure 1). Hereafter, the LULC data for the base year 2000, which is in Geographical Information System (GIS) digitized formats, is called TFS 2000 LULC. It was used to prepare biogenic emissions data and to perform meteorological simulations to keep consistency in the input data for air quality simulations. To resolve problems inherent with the TFS-LULC data such as the misinterpretation of land use types, the LULC data were recalculated and revised, and a new class residential forest was added to better simulate the meteorological changes over the two decades.

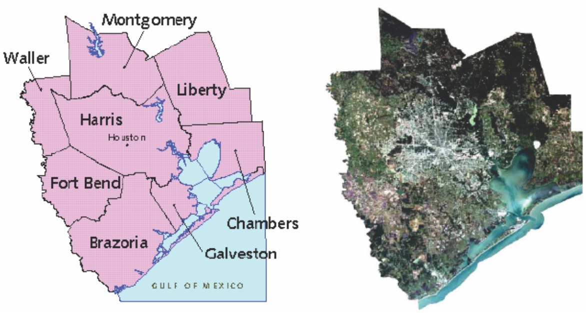

Figure 1. The study area consisting of the eight counties around Houston, Texas, including Brazoria, Chambers, Fort Bend, Galveston, Harris, Liberty, Montgomery, and Waller (left). Corresponding LANSDAT image (right) (from GEM, 2003).

2.2 Modifications made to TFS 2000 LULC

While performing preliminary research using the LULC data, we found some inconsistent LULC information and reprocessed some of the original LULC data. The LULC classes used in this study were shown in Table 1.

2.2.1 Replacing the barren land cover type with the agriculture and the urban barren in land use

The LANDSAT pictures were taken around October, 2000. After reviewing the details of the LULC data, we have suspected that the barren class shown in the picture may represent the agricultural land after harvesting but and before replanting and seeding. Because the air quality modeling episode used is the TexAQS 2000 experiment period August 15 – September 15, 2000, the actual land cover (LC) must have been the agricultural land rather than the barren. Until now, we used only LC data for the meteorological and emissions processing based on the assumption that the vegetation cover is the most important parameter determining the surface moisture and energy balance. However, in order to resolve the problem of misrepresentation due to the seasonal change, we utilized the TFS land use (LU) data to replace the incorrect seasonal LC data. The barren class in LC can be matched to 1) the agriculture and barren, 2) urban barren, and 3) others like airport, in part, in LU categories. By assuming the agriculture and barren class in LU represents all the agricultural area in August, we revised the fractional land cover data for the agriculture and the barren classes in LC

Table 1. LULC classes used for MM5 simulations and biogenic estimation in GloBEIS.

No.	MM5 classes	GloBEIS classes
1	Barren	Urban built
2	Forest Broadleaf	Northern broadleaf
3	Forest Coniferous	Northern coniferous
4	Forest Mixed	Northern mixed
5	Grass	Northern agriculture/range - Chambers, Harris, Liberty, Montgomery and Waller Southern agriculture/range – Brazoria, Ft. Bend and Galveston
6	Impervious	Urban built
8	Water	Water
9	Agriculture	Northern agriculture/range - Chambers, Harris, Liberty, Montgomery and Waller Southern agriculture/range – Brazoria, Ft. Bend and Galveston
10	Residential	Urban residential
11	Urban	Urban built
12	Residential Forest	Calculated

2.2.2 Adding residential and other urban subclasses

Using the residential and urban classes in the LU data, we made additional classes in LC to have better meteorological simulations representing the urban heat island around downtown Houston. It was assumed that the residential class, if any, replaced all other classes except those for trees (broadleaf, coniferous and mixed forests in LC) to keep them in as many separate classes.

2.2.3 *Creating residential forest for MM5 simulation*

MM5 uses only the dominant LULC class and therefore small changes in the LULC data would not be reflected in the moisture and energy budget computation. To enhance these LULC change in the meteorological modeling, we have created one more LC class, Residential Forest, to capture more sensitively the change of fractional vegetation coverage in the residential class. This class is also used for the projection of LULC for the future year 2010, and it plays an important role of detecting the vegetation change due to the urbanization.

This class is added for cells where 1) Residential is the dominant LU and 2) total forest area (broadleaf, coniferous and mixed forests) takes over more than 30% of cell coverage. Since GloBEIS uses the fractional coverage, the new dominant LULC type reclassification does not affect the biogenic emissions processing.

2.3 LULC projection for future and past years

There are several problems in utilizing the 1992 NLCD directly for studying the effects of LULC changes on meteorology and biogenic emissions because of the wildly different LULC categories used between the TFS 2000 LULC and NLCD 1992 datasets. Therefore, we have utilized the NLCD data only for the estimation of fractional vegetation changes for each 1-km grid cell. In this study, we have used TFS 2000 LULC data as the basis of the past and future year projected LULC data. For example, the TFS 2010 LULC data was generated by projecting the 2000 data utilizing these fractional changes for each cell.

To produce the projected data for the LULC classification listed in Table 1, we have used five LU classes provided by the TFS; Forest, Agriculture, Residential, Urban Built and Water as the surrogate projection classes. Since we have utilized different LULC classes for the projection, it was necessary to regroup the 12 TFS LULC categories corresponding to the representative projection classes.

Applying the same methodology, TFS 2000 LULC data was also backwardly projected for the past year 1992. Figure 2 depicts how the dominant LULC data changes among three different years as used in the MM5 simulations. Based on the LULC data for the base and projected years, it was expected that the temperature increases in response to the growth in the urban categories like residential and urban replacing grass and forest.

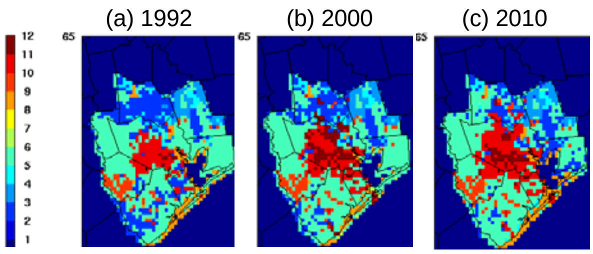

Figure 2. The dominant LULC class by cell for the base year and for the projected years. The urban and residential dominant cells (red colors) increase from the past to the future. The colors (i.e., integer numbers) correspond to the LC classes defined in Table 1.

3. METEOROLOGICAL SIMULATIONS

To study effects of the land cover change on air quality, it would be ideal to utilize the meteorological and emissions processing results that fully take into account for the effects of the LULC data for air quality modeling. Thus, instead of the USGS data implemented in MM5, we have conducted a set of MM5 sensitivity tests with the different TFS LULC datasets for different years.

Figure 3a shows the dominant LULC patterns derived from the original USGS 25-category dataset for the 1-km resolution domain where the Houston urban area is classified as a large contiguous impervious area (represented in red color), which does not distinguish among urban, residential, planted trees and road LU types. To resolve the Houston urban characteristics more accurately, an updated land use data for the eight county area surrounding Houston, called TFS-LULC 2000, was produced using the LANDSAT satellite imagery and ancillary datasets (GEM, 2003). Figure 3b shows the 1-km dominant LULC patterns derived from the TFS 2000 LULC which represents the Houston downtown area is consists of grass, forest, and urban concrete land use types. MM5 with the modified NOAH land surface model (Cheng et al., 2003) was used to establish effects of the LULC changes on the meteorological data.

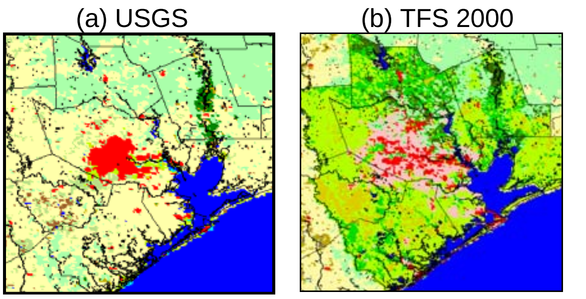

Figure 3. Dominant land types for 1-km resolution domains derived from USGS and TFS 2000 LULC.

4. BIOGENIC EMISSIONS

Biogenic emissions estimates can be modified by the changes in the land use land cover data (including vegetation types and the LMD data), and the changes in the canopy temperatures. In this section we compare different biogenic emissions among three years; 1992, 2000, and 2010, using different LULC data and canopy temperatures simulated from MM5.

4.1 Biogenic emission estimation method

To estimate biogenic emissions with the TFS LULC, we used the GloBEIS version 3.1 (http://www.globeis.com/) (Guenther et al., 1998; Yarwood, 1999 & 2002). We revised the internal database to couple with the TFS LULC data and leaf mass density (LMD) data prepared for HGA. Figure 4 represents changes in leaf mass density of 'Quercus' (oak), one of major isoprene emitting tree species, between 1992 and 2010. Biogenic emissions for three difference years were produced with the 4-km resolution meteorological inputs such as 10-m temperature from MCIP (estimated from the MM5-NOAH simulations described above). Because MM5 simulations may predict spurious cloud information, we kept the TCEQ GOES satellite-derived photo-synthetically active solar radiation (PASR) data for the biogenic emissions processing. The canopy temperature field, which was necessary for the biogenic emission processing, was derived from the MM5 simulations with different TFS LULC datasets prepared for each year as shown in Figure 2. A detailed description on the processing steps can be found from Byun et al (2005).

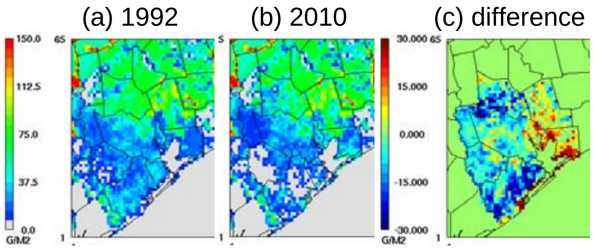

Figure 4. Changes in Quercus (Oak) between 1992 and 2010 for the HGA 8 Counties.

4.2 Comparison of biogenic emissions for 1992, 2000, and 2010

Using the modified GloBEIS version we estimated biogenic emissions for three different years; 1992, 2000 and 2010. Figure 5 compares the biogenic emission estimates for isoprene among different years. The result shows the decreasing tendency of the isoprene emissions due to reduction of the vegetation such as decline of tree species emitting isoprene and the increase of the urban areas. Compared to year 1992, isoprene emissions for the Houston-Galveston 8-County area have decreased by ~ 10 % in year 2010.

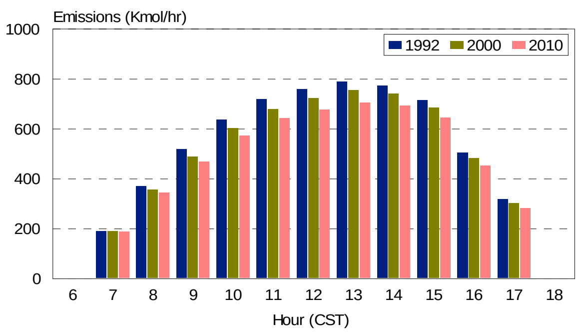

Figure 5. Diurnal cycle of daily averaged isoprene emissions for the HGA 8 Counties estimated with different LULC data and canopy temperatures for years 1992, 2000 and 2010 during the period of August 22 ~ August 31.

Figure 6 presents the changes in isoprene emissions for each county. In general, between years 1992 and 2010, isoprene emissions decrease except for Chambers and Liberty Counties where new forest areas appear. Except for these two counties, the rest of counties show decreases in isoprene emissions. In 1992, isoprene emissions from Harris, Liberty and Montgomery counties (the major emitters) amount to ~ 70 % of the total for the HGA 8 Counties.

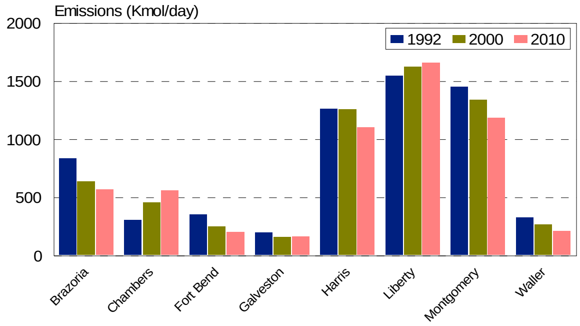

Figure 6. Isoprene emissions for each County estimated with different LULC data and canopy temperatures for years 1992, 2000 and 2010.

5. CAMx SIMULATION RESULTS

Using the meteorological conditions and biogenic emissions estimated as described above, CAMx (Environ, 2002) simulations for the three different LULC years were made. The MM2CAMx processor was used to prepare CAMx-ready meteorological data from the MM5 simulations. To evaluate the impact of the LULC change, we have selectively utilized the 4-km resolution MM5-NOAH predicted temperature fields to estimate biogenic emissions. For example, the modified MM5-NOAH version was run with the TFS LULC datasets but only the temperature fields were taken for processing biogenic emissions and performing air quality simulations. The wind and PBL height fields were provided by the MM5-GOES simulations because the main goal of this study was to assess the impact of the LULC change on the HGA air quality and we did not intend to have the changes in the transport conditions, which might have significantly influenced air quality assessment results.

To evaluate the overall impacts of the land cover changes on temperatures, on biogenic emissions, and thus on ozone concentrations, we simulated CAMx using three different sets of LULC and temperature inputs prepared. The daily maximum ozone concentrations for August 25th and the differences among the three LULC years are presented in Figure 7. The general pattern that the high ozone plume appears around Harris County was identical among the three simulations, reaching the maximum concentrations at around 150 ppb. The difference plots show that the maximum ozone concentrations in year 2000 were higher than those in year 1992. On the contrary, the change in the maximum concentrations between 2000 and 2010 was smaller than that over the previous decade. When years 1992 and 2010 were compared, the downwind area of the Ship Channel showed increasing ozone concentrations, but the southern Harris County area showed decreasing ozone concentrations. The same comparisons for August 30, however, presented decreasing ozone concentrations in the south of the downwind area of the Ship Channel (not shown). As shown here, the ozone concentrations can increase and decrease with the changes in the LULC because the changes in the biogenic isoprene emissions result in different ozone production characteristics at different places when the anthropogenic emissions are kept constant.

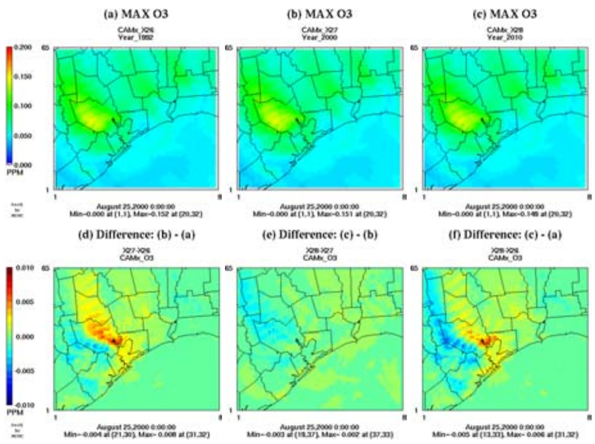

Figure 7. Ozone concentration fields predicted for different years; 1992, 2000 and 2010 (from left side) and the differences for August 25.

Figure 8 presents changes in the daily maximum ozone concentrations between 1992 and 2000, corresponding to changes in daily isoprene emissions and daily maximum ambient temperature at surface level over the same period. To explain these changes, we must also consider the positions of the cells with high ozone concentrations relative to the biogenic emissions source regions depending on the wind directions.

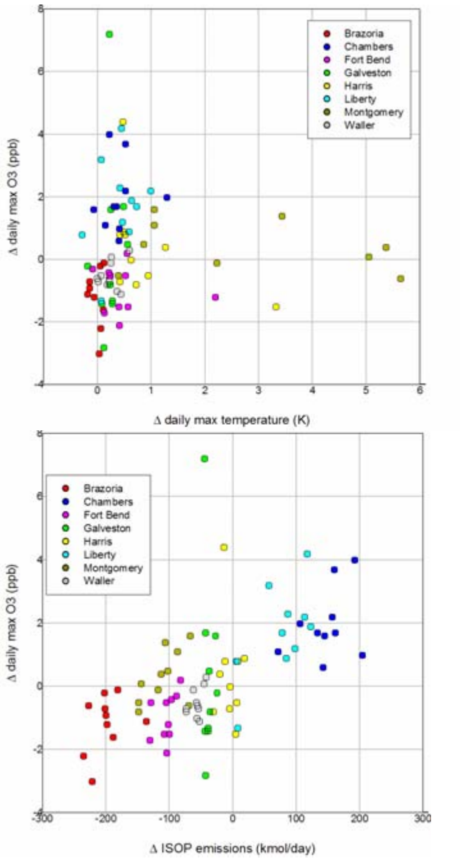

Figure 8. Correlations among changes in daily isoprene emissions, maximum canopy temperature and maximum ozone concentrations between 1992 and 2000 for each county during the simulation period. Each dot represents each county and each day during the simulation period.

6. CONCLUDING REMARKS

To study the overall impacts of the LULC change on biogenic emissions, on air temperature, and on air quality, we used biogenic emissions inputs and MM5-NOAH air temperatures predicted with different LULC datasets for the air quality simulations while using the same wind fields, planetary boundary layer heights and other meteorological parameters from the MM5-GOES simulations.

We have noticed that the domain total biogenic emission estimates for isoprene decreased due to the reduction of the vegetation area. Compared with year 1992, isoprene emissions for the Houston-Galveston 8-County area have decreased by 10 % in year 2010. The daily maximum ozone concentrations over the HGA were results of the combined effects of biogenic emissions and meteorological changes caused by different LULC data depending on the simulation conditions. For example, on August 25th and 31st the ozone concentrations are reduced in year 2010 compared to year 2000, but on August 30th and September 1st ozone increased in the future year.

Because the change patterns of LULC were different, we analyzed the results for each county. Between years 1992 and 2010, isoprene emissions decrease except for Chambers and Liberty Counties and along the coast where new forest areas appear. Isoprene emissions increased for the Chambers due to the increase in the coastal forest areas and for the Liberty County due to the expanded areas of bottom oak forest.

In general, ozone concentrations decreased with the decreased isoprene when temperature increases were not much discernable. However, during the second half of the episode when air temperatures were high and local weather effects dominated, the increases in surface temperature due to the deforestation between 1992 and 2000 were much more apparent. For days August 30th to September 1st, ozone concentrations increased in spite of the decrease in the biogenic emissions over and downwind areas of the HGA eight counties for 2000 than 1990. The continued decrease in isoprene emissions and little changes in surface temperatures resulted in lower ozone concentrations in 2010 than in 2000. Therefore, interestingly, the maximum ozone concentrations for 2010 were at least not worse than either 1992 or 2000 LULC cases.

The present study reveals that urban deforestation results in higher ozone concentrations due to the temperature effects on the air quality. Conversely, if new trees with minimal isoprene emissions were planted, the ozone concentrations over and downwind urban areas would be reduced. Moreover, it is expected that the benefits become more effective over the region where there is no influence of large anthropogenic direct VOC emissions sources. Rural and suburban areas downwind of urban and industrial areas are some of the examples.

8. Acknowledgment

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