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**Modeling Effects of Land Use/Land Cover Modifications on the Urban
Heat Island Phenomenon and Air Quality in Houston, Texas**

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Project Summary

This report summarizes research findings of the Houston-Galveston area (HGA) urban heat island modeling project. The primary goal of the research is to study how changes in land use (LU) and land cover (LC) impact on air quality in the HGA. Urbanization of mega-cities like Houston occurs with significant changes 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 effects (UHI) in the region. New tree planting programs such as Houston Green project have 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. We have conducted 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 HGA.

(1) Effects of Land use and land cover modification on the urban heat island

Recently, the Texas Forest Service (TFS), with the support of Texas Commission on Environmental Quality (TCEQ), has compiled a new high-resolution (30-m) 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 the LANDSAT satellite imagery and ancillary datasets for the base year 2000. A supervised classification process using image processing software was employed to define the eight land cover classes and fifteen land use classes. Also, a comparative LULC data for the reference year 1990 was developed using the satellite imagery of 1990., in particular, to assess the changes in the tree and vegetation cover between 1990 and 2000. We will call these datasets as TFS-LULC 1990 and 2000, respectively.

The availability of consistent satellite-derived LULC datasets for the years 1990 and 2000 provides an opportunity to isolate the effects of LULC modification on air quality with much less uncertainty than comparing the results from the two entirely different LULC datasets. The statistics on forest cover change between TFS-LULC 1990 and 2000 across the entire 8 counties are as follows: Between 1990 - 2000, we lost 868,421 acres of forest (15 % of the 8-county area). Of the lost forest area is 77% because grass-range land, 14% barren, 6% impervious surface, and 3% water. On the other hand, the new forest area of 293,182 acres (5% of the 8-county area) was 76% broadleaf, 9%

coniferous, and 15% mixed forest. About 24% of the area had no change in the forest cover between 1990 and 2000.

Different vegetation and land cover conditions can lead to different surface meteorological conditions including canopy and ambient air temperatures. We performed MM5/NOAH meteorological model simulations using the TFS-LULC 1990 and 2000 data to characterize meteorological differences caused by LULC changes over the ten year time span. Simulated air temperatures for 2000 were in general lower than those for 1990 in the HGA eight county area, especially in Harris County. Air quality simulations with these different air temperatures, with all other meteorological inputs kept the same as in the MM5-GOES case, showed that higher ozone concentrations were predicted with higher ambient temperatures. We chose this approach to isolate the effects of temperature change on ozone. This demonstrates a potential benefit of cooling of an urban atmosphere. However, a study conducted by UH earlier with MM5 using standard USGS-LU:C data showed that such effects may be difficult to distinguish from other effects when combined with the accompanying changes in the winds and boundary layer heights.

(2) Effects of land use and land cover modification on the biogenic emissions

Biogenic emissions estimates can be changed by both changes in the land use land cover data and changes in the canopy temperatures. One of the main purposes of this study was to compare the GloBEIS3 results with the LULC data TCEQ has been utilizing (TCEQ-LULC) and with the TFS-LULC data. Initially, to isolate the impact of the vegetation cover differences on the biogenic emissions, we utilized the same observed temperature and GOES-derived radiation fields used by TCEQ. Outside the HGA, the existing TCEQ biogenic emission data were used without modification. The results showed that the TFS-LULC 2000 data resulted in about 20% higher biogenic NO emissions but about 10% lower isoprene and CO emissions than those with the TCEQ-LULC data. Spatially, the isoprene emissions decreased significantly in Liberty County where the ‘bottom oak’ tree species is more predominant in the TCEQ-LULC data than in the TFS-LULC data. We observed higher isoprene emissions around Harris and Chambers counties with the TFS-LULC case and therefore higher ozone concentrations in downwind areas, up to 20 ppb, than in the TCEQ-LULC case. Because biogenic NO emissions depend more on the land cover types than on the vegetation classification, the different land coverage and NO emissions factor associated with each land cover class in the TFS-LULC lead to different NO emissions. CO and ISOP emissions are affected both by the the land cover distribution and the LMD applied. The differences in biogenic

emissions become especially large during afternoons when both PASR and canopy temperatures are high.

We explored changes in the biogenic emissions corresponding to the changes in the LULC data and the canopy temperatures estimated by the MM5/NOAH simulations for 1990 and 2000, as well. Effects of land cover changes on the biogenic emissions in the HGA during the past ten year period were studied by processing GloBEIS3 with the TFS-LULC 1990 and 2000 datasets, in which the TCEQ-LULC data is replaced with the satellite-derived data inside the HGA 8 county area. Between TFS-LULC 1990 and 2000 data, isoprene emissions increased in Liberty County and decreased in other counties such as Harris, Chambers and Montgomery, corresponding to the creation and the loss of forests. This resulted in about a 5-10% decrease in the domain-total isoprene emissions between 1990 and 2000.

(3) Effects of Land use and land cover modification on the air quality in the Houston-Galveston area

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 (PBL) heights and other parameters from the MM5-GOES simulations. The lower isoprene emissions estimated with the LULC 2000 data (corresponding to the reduced broadleaf forest area) and the lower air temperature (due to the changes in LULC from barren to grass/range) lead to lower ozone concentrations over and downwind areas of the HGA eight counties for 2000 than 1990. It was found that, in general, daily maximum ozone concentrations decreased across the domain as ambient temperatures decreased. However, the surface ozone concentrations are affected more significantly by changes in isoprene emissions due to changes in land cover.

The inconsistent results in the air temperature trend between 1990 and 2000 somewhat obscure the prime target of the present study, mainly to quantify the effects of urban deforestation on the air quality. However, the response of the air quality system to the changes in the LULC and temperatures behaves as expected. The present study allows us to deduce to a conclusion that reduction of urban heat island effects and selective planting of tree species that produce less isoprene emissions will have beneficial effects on improving ozone air quality in the HGA.

To isolate the effects of deforestation on air quality, UH has suggested to TERC a supplemental project using TFS-LULC 2000 as reference data to modify the forest fraction for a future projection year, say 2010. The rate of change of the forest area can be computed using a better method than extrapolating from the TFS-LULC 1990 and 2000. TERC approved the supplemental project and USDA has generated the forest trend data using the NLDC LULC. There are other shortcomings in the present study, therefore additional studies, such as the effects of increased vegetation on dry deposition, effects of LULC change on the wind and boundary layer heights, and simulations with projected LULC data, will be necessary.

8. SUMMARY AND ON-GOING STUDIES

As shown in the analyses above, there were some inconsistencies in the modeling results of air temperatures and biogenic emissions due to the differences in the time the LANDSAT 1990 and 2000 pictures were taken. To isolate effects of deforestation on the air quality from the seasonal changes in the land cover data, we have suggested TERC a supplemental project, in which the TFS-LULC 2000 is used as the reference data to modify forest fractions for the future projection year, say 2010. The rate of change of the forest area could be computed using a more consistent data than the TFS-LULC 1990. TERC approved the supplemental project and USDA has generated the forest trend data using the US Geological Survey (USGS) National Land Cover Dataset 1992 (NLCD 92). To overcome these shortcomings in the present study, it will be necessary to perform additional studies, such as the effects of increased vegetation on the dry deposition, effects of LULC change on the wind and boundary layer heights, and simulations with a projected LULC data..

8.1 *Summary of Present Results*

The availability of satellite-derived LULC datasets for the year 1990 and 2000 provided an opportunity to study the effects of LULC modification on air quality. The statistics on forest cover change between TFS-LULC 1990 and 2000 across the entire 8 counties are such that between 1990 - 2000, we lost 868,421 acres of forest (15 % of the HGA 8-county area). Among this, 77% of the lost forest area is transformed into the grass-range land and 14% barren, 6% to impervious surface and 3% to water. On the other hand, the new forest area of 293,182 acres (5% of the 8-county area), with 76% broadleaf, 9% coniferous and 15% mixed forest categories; About 24% of the area there was no change in the forest cover between 1990 and 2000. No-change in forest 1990 and 2000: 1,349,581.566 Acres 6,068,428 points (24% of the 8-county area)

CAMx simulations showed that isoprene emissions in Harris and Montgomery decreased between 1990 and 2000, which lead to the decrease in ozone concentrations by up to 20 ppb in year 2000. Compared to the TCEQ-LULC, TFS-LULC 1990 showed higher isoprene emissions around Harris and Chambers and increased ozone concentrations in downwind areas. We noticed slightly higher isoprene emissions in Harris County with the 1990 data than with the 2000 data, and thus higher ozone levels with the 1990 data although the magnitude varied each day depending on whether high biogenic emissions areas were located in the downwind of the anthropogenic NO_x and VOC sources.

Second, we studied if there were benefits of cooling the urban atmosphere on improving HGA air quality. Although temperature differences showed only limited effects on the isoprene emissions, we observed slight increase in ozone maximum with increased air temperatures due to the effect of the Arrhenius reactions of the air chemistry reactions. The present study shows that the effects of air temperature can induce about 10 ppb higher ozone concentrations in HGA. However, due to the nonlinear effects, the increase may not be as prominent when combined with the effects of changes in biogenic emissions.

The simulated air temperatures with the TFS-LULC 2000 were generally lower over the HGA 8-county area, especially in Harris County than with the TFS-LULC 1990, because the increased grass land in the 2000 data, probably an artifact that the 1990 LANDSAT picture was taken in December. TFS-LULC 2000 presented the decreased 'barren' class, which usually causes high temperature in the MM5 simulations. On the other hand, 'grass' class in the TFS-LULC 2000 was dramatically increased filling in the lost forest and barren areas between 1990 and 2000. Since the land use class of 'grass' has almost the same cooling effects, the simulated air temperatures with the 2000 data has decreased.

To study the overall impacts of the LULC change on biogenic emissions, on air temperature and on air quality, we used the modified biogenic emissions and MM5-NOAH predicted air temperatures for air quality simulations. Note that we used the same wind fields, planetary boundary layer (PBL) heights and other parameters obtained from the MM5-GOES simulations. The lower isoprene emissions with the LULC 2000 data corresponding to the reduced broadleaf forest area and the lower air temperature due to the changes in LULC from barren to grass/range lead to lower ozone concentrations about 20 ppb over and downwind areas of the HGA eight counties for 2000 than 1990. It was found that, in general, daily maximum ozone concentrations increase across the domain as ambient temperatures increase. However, time series comparisons made at the CAMS and other super sites show consistent results that changes in ozone concentrations due to different ambient temperatures are not as important as those due to the land cover changes.

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 have beneficial effects on improving ozone problems. A further study on the additional effects of the vegetation change, such as the effects of increased vegetation on the dry deposition and simulations with a projected LULC data will be performed through the follow-up study.