STUDY THE INTERACTION BETWEEN METEOROLOGY AND CHEMISTRY ON THE HOUSTON'S HIGH OZONE PROBLEM USING CMAQ/MM5

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1. INTRODUCTION

The Houston-Galveston-Brazoria area (HGB) is known as the severe ozone non-attainment regions in the states (Allen et al, 2002). The Houston's high ozone concentration is contributed from anthropogenic (e.g. Ship Channel) and biogenic emissions. In addition to the emissions, meteorology also contributes to Houston's high O_3 concentration. The O_3 distribution in the atmosphere is determined by complex interaction between meteorology and chemistry. Houston is located near the Gulf of Mexico and Galveston Bay, affected by the land-sea breeze flow which influences the transport/dispersion of local pollutants (Nielsen-Gammon, 2002).

The meteorological factors like land-air surface interactions, turbulent mixing, dry deposition processes, and wind transport are key parameters determining O_3 concentrations. For example, turbulent mixing layer height determines the vertical mixing of O_3 precursors, such as nitrogen oxides (NO_x) and volatile organic compounds (VOCs). Under shallow mixing layer and light wind conditions, the dispersion of air pollutants is limited allowing the O_3 concentrations to build up. On the other hand, mixing of NOx in deeper urban boundary layer like in Houston downtown, can lead to high O3 concentration aloft.

The focus of this study is on the treatment of the land surface processes. Previously, we have performed several sensitivity studies to improve the meteorological simulations of the HGB area. One of the issues is the reliability of the land use land cover (LULC) data. MM5 uses USGS-25 category land use data where Houston city is categorized as a complete impervious surface. With this dataset, MM5 predicted higher daytime maximum temperatures than the observations in the Houston downtown area. In reality, Houston city has around 30% tree coverage realizing substantial evapotrasporation processes. To correct the high temperature bias while using the USGS LULC data, we added effects of the canopy water to account for the man-made vegetation evaporation processes in the urban area. Furthermore, we improved wind predictions by correcting the momentum flux and convective velocity scale inside MRFPBL scheme (Cheng and Byun, 2003).

Recently, the new LULC dataset was developed from LANDSAT multi-spectral images taken in September 2000 (GEM, 2003) for the HGB eight counties comprising of Brazoria, Chambers, Fort Bend, Galveston, Harris, Liberty, Montgomery, and Waller. The dataset is referred to as TFS-LULC. This new LULC dataset distinguishes the real impervious surface and other urban LULC categories accurately. We expect that with this dataset, the artificial addition of the canopy water will not be necessary for the MM5 simulations. The primary goal of the present research is to utilize the high-resolution LULC dataset for the meteorological modeling. The secondary goal is to demonstrate the effects of modified meteorological inputs on the air quality prediction of the Houston's high O_3 episodes.

2. MODEL CONFIGURATION AND INPUT DATA

In this study, MM5 Version 3 Release 6 (MM5v3.6.0) (Grell et al., 1994) was used. The simulation period is from 22 Aug. to 01 Sep., 2000. Figure 1 shows the domain setup. Domain configurations for D1 to D4 are listed in Table 1.

MM5 physical options applied include: Grell cumulus scheme on the 108-, 36- and 12-km domains, and no cumulus scheme on the 4-km domain; MRF PBL scheme; Dudhia simple ice microphysical scheme, cloud-radiation scheme and the modified NOAH LSM (Chen et al, 2001). The first guess and boundary conditions are from the NCEP Eta model.

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Upper-air analysis nudging of wind, temperature and water vapor is used without the surface analysis nudging. Observation nudging of wind was used in the 4-km domain.

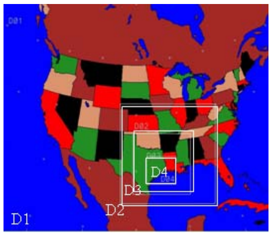

Figure 1. Meteorological model domain setup.

Table 1. Domain configuration.

Domain	# of x	# of y	Z level	dx,dy (km)
1	53	43	43	108
2	55	55		36
3	100	100		12
4	136	151		4

MM5 simulations at 4-km resolution domain were evaluated with observation and wind profiler data. Figure 2 shows the locations of the available CAMS (Continuous Ambient Monitoring Station) sites, which provided the observed surface wind, temperature and air pollutant concentrations.

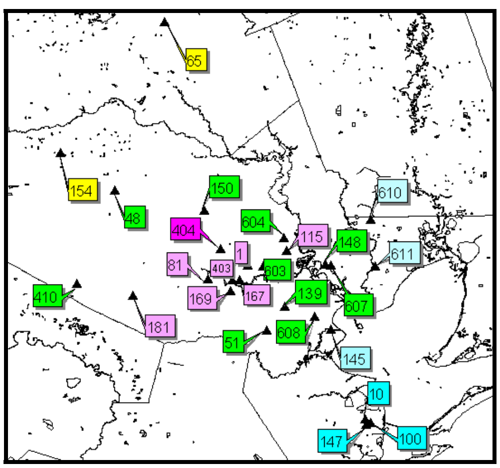

Figure 2. Location of the CAMS measurement sites.

Anthropogenic emissions in the CAMx-ready format provided by TCEQ were used in this study. The emissions that include highly reactive volatile organic compounds for imputation were processed through the EPS2 (Emissions Preprocessing System Version 2) system. Prior input to CMAQ, the emissions inputs were converted into the CMAQ-ready format, applying the plume-rise with MM5-MCIP outputs. Biogenic emissions estimated using GloBEIS3 were merged to the anthropogenic emissions for air quality simulations for the purpose of confining the meteorological effect. CMAQ version 4.3 (Byun et al, 1999) was used for air quality modeling.

3. LAND USE AND LAND COVER DATA

The sensitivity studies were designed to accommodate different LULC data inside MM5. First, MM5 simulation was performed using the original USGS land use dataset. Figure 3 shows the dominant LULC patterns derived from the original USGS 25-category dataset for the 1-km resolution domain (panels (a)). Here, 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 land use types. Compared to this, the Houston urban characteristics are resolved more accurately in the TFS-LULC datasets.

Panel (b) of Figure 3 shows 1-km dominant LULC patterns derived from the TFS-LULC dataset. It shows detailed LULC features of Houston’s central city area, including grass, trees, urban hard surface and residential land use types. Another noticeable difference between the two land use datasets is that most of the dry/cropland type in the USGS data is replaced with the grass type in the TFS-LULC while the land surface parameters specified for the MM5 simulations do not differ much between the dry/cropland and grass land use types. A MM5 simulation (namely MM5-TFS) was performed by replacing the original USGS 25-category LULC with the TFS-LULC data for the 4km resolution domain.

4. RESULT OF METEOROLOGICAL SIMULATION

The MM5-USGS simulation included the anthropogenic canopy water effect in the urban cells to reflect the vegetation evapotranspiration processes. In the MM5-TFS simulation we removed this artificial modification expecting that the new dataset resolved the Houston’s LULC classes accurately such as distinguishing the grass and residential types from the impervious surface areas. Inside Houston urban areas, a large portion of the impervious surface LULC type specified in the USGS data was replaced with the residential type in the TFS-LULC dataset.

Figure 4 presents the scatter diagram between model simulation and CAMS observation data for 1.5-m temperature. With the use of the more accurate and updated TFS-LULC map, the MM5-TFS simulation (panel (a)) shows better agreement with observation data especially in the maximum temperature prediction than those from the MM5-USGS simulation (panel (b)). Most of the CAMS sites, the MM5-TFS simulation, with more accurate LULC data and improved NOAH LSM, show better agreement than the MM5-USGS simulation.

Figure 5 is the spatial plot of wind speed and wind direction from (a) MM5-USGS, (b) MM5-TFS simulations and (c) the difference plot at 22UTC, August 30th. MM5-USGS shows stronger and faster onshore flow than the MM5-TFS simulation. The weaker onshore flow in MM5-TFS simulation could be caused by the land developed in the last decade along the coast line which is not represented in the outdated USGS data but correctly represented in TFS-LUCL datasets. The existence of these lands could slow down the movement of the air flow from Gulf of Mexico. Figure 6 is same as Figure 5 but showing ground temperature (TG) field. The TG distribution corresponds to the land use type where urban impervious surface shows higher temperature prediction. Figure 7 compares planetary boundary layer (PBL) height fields. There is a significant difference in the PBL height at the Lake Houston (panel (c)) (white circle specified in the figure), which is nearby the emission source. TFS-LULC data correctly represents the Lake Houston as water body land use type which results in the lower PBL heights.

5. RESULT OF CMAQ SIMULATION

CMAQ simulations are performed using the two different meteorological inputs. Simulation with MM5-USGS dataset is named CMAQ-USGS; simulation with MM5-TFS dataset is named CMAQ-TFS. Figure 8 shows spatial plots of O_3 concentration. There is a significant difference in the downwind area of the Lake Houston. CMAQ-TFS shows higher maximum O_3 concentration which is in consistent with lower PBL height prediction. The distribution of O_3 concentration is consistent with the temperature distribution where urban areas predicts higher temperature inducing more active photochemistry; thus, higher local O_3 production.

Several CAMS sites located nearby Ship Channel show the O_3 concentration hits ~200 ppb value especially from Aug. 29th to Aug. 31st. CMAQ-TFS has better resolved land use map and well-simulated meteorological field but maximum O_3 value is still underestimated. Since Ship Channel is a very confined area with the concrete surface covered on the ground, which is also affected by the adjacent water body, the meteorological condition is difficult to simulate. We are hoping that the 1-km simulation with the detailed land use map is able to generate the realistic meteorological field in the Ship Channel area.

One of the CAMS sites (408) shows higher O_3 concentration on Aug. 25th from CMAQ-TFS simulation (Figure 9, panel (a)). 6-hr backward trajectory plot are generated for corresponding MM5-USGS and MM5-TFS simulations (Figure 9, panel (b) and (c)) on Aug. 25th UTC 2200. The trajectory plot shows that wind is more stagnant in the MM5-TFS simulation where O_3 and its precursor pollutants accumulate closer to the source area.

The daily maximum ozone concentration plot over the (a) Harris and (b) Brazoria counties (Figure 10) shows that the meteorological changes caused by different LULC data on air quality vary day by day, depending on the simulation conditions. The major difference from Aug. 29th to Aug. 31st in Harris County was caused by the shallow PBL height near Lake Houston in MM5-TFS simulation.

6. SUMMARY

USGS LULC dataset displays Houston city as a large contiguous surface while the TFS-LULC describes the urban impervious surface areas as confined to a narrow and isolated congregation of urban development. The meteorological simulation is improved with the more accurate and updated land use map.

In general, ozone concentrations are affected by PBL height, temperature and wind speed. Daily maximum HGB ozone concentrations are resulted from the lower PBL heights. The Lake Houston is correctly represented as water land use body in TFS-LULC data which predicts lower PBL heights.

Results of this study revealed that use of different LULC datasets affected the simulated meteorological conditions and ozone levels significantly. Higher ozone concentrations were observed either near the place where the PBL heights were shallower or in the places where the photochemical reactivity were larger due to the locally higher air temperatures and changes in the transport conditions.

However, the current 4-km CMAQ simulation could not simulate the observed maximum O_3 concentration at ~200 ppb level. We are hoping that MM5 simulations at the higher resolution (e.g., 1-km) with the more accurate and detailed land use map, may be able to provide more realistic meteorological conditions for CMAQ modeling especially for the high emission source area near the Ship Channel.

7. REFERENCES

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(a) (b)

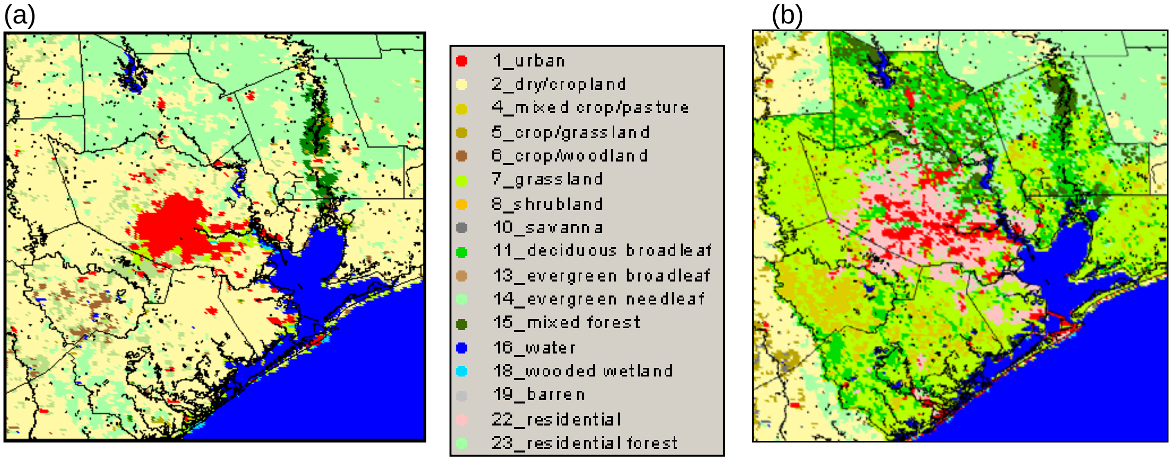

Figure 3. Dominant land use types for 1-km resolution domain derived from (a) original USGS 25-category; and (b) TFS-LULC dataset.

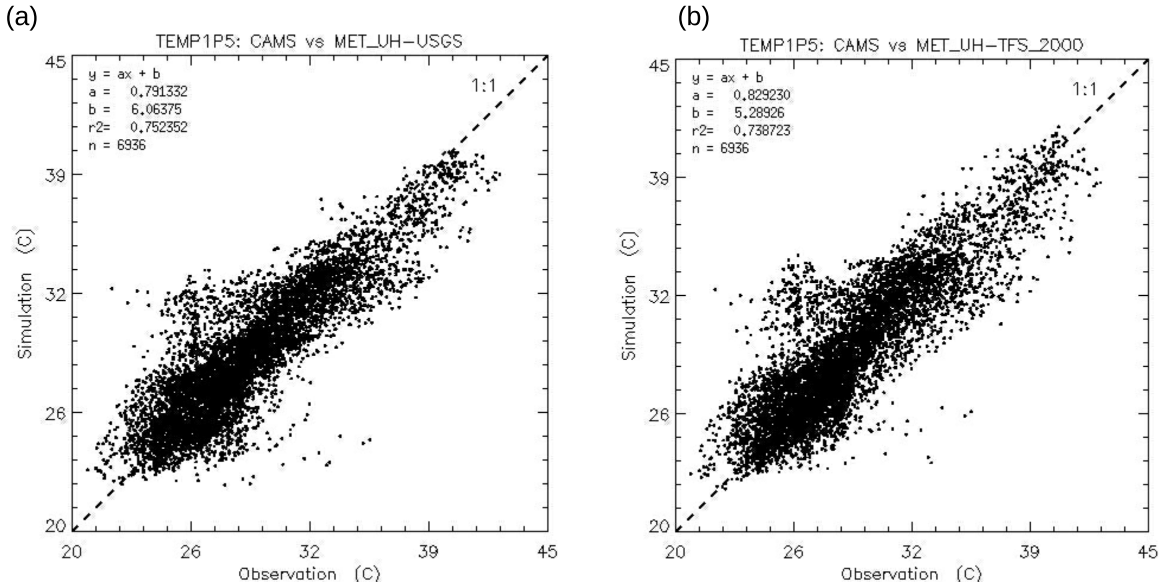

Figure 4. Scatter diagram of 1.5-m temperature between (a) MM5-USGS; (b) MM5-TFS simulations and CAMS observation data.

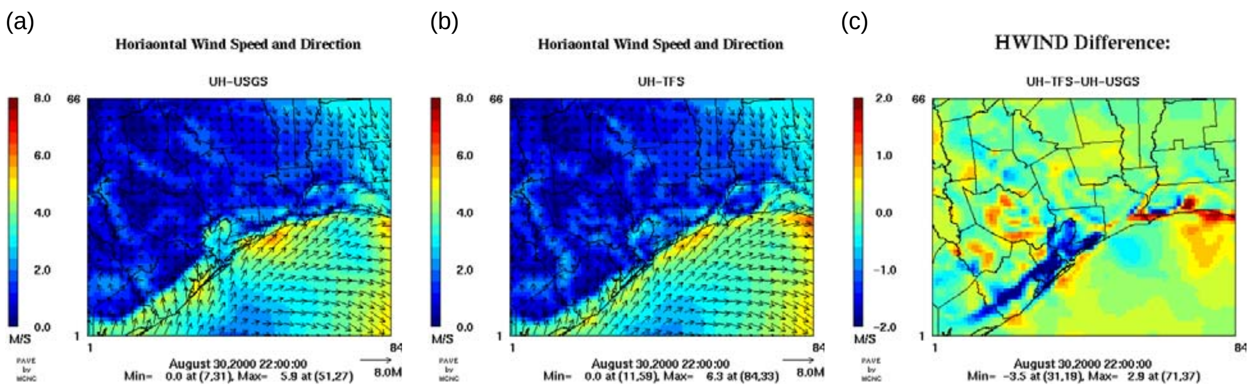

Figure 5. Spatial plot of wind speed from (a) MM5-USGS; (b) MM5-TFS simulations (c) difference plot on UTC 2200 Aug. 30.

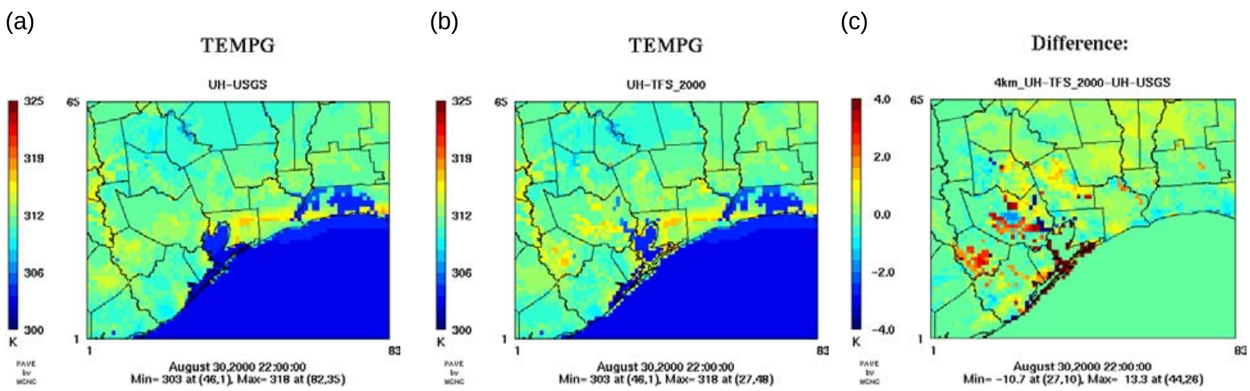

Figure 6. Same as figure 5 but showing ground temperature distribution.

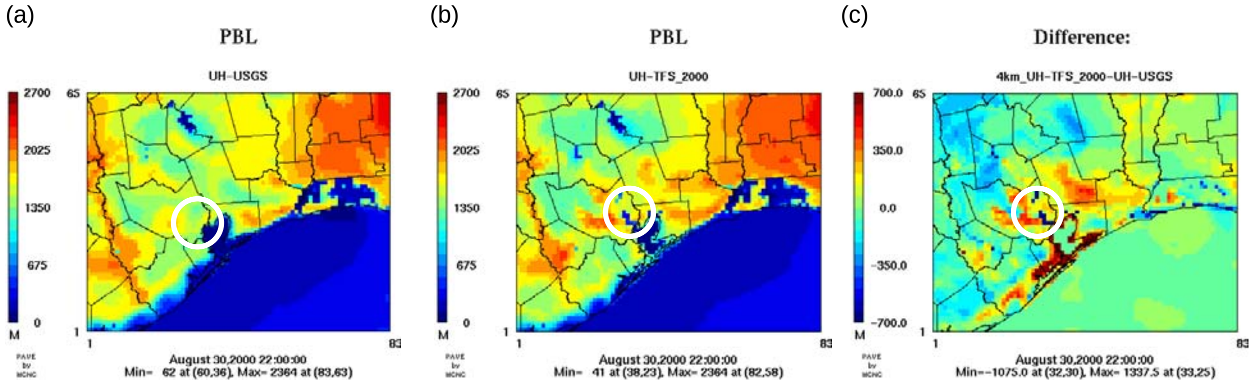

Figure 7. Same as figure 5 but showing PBL height distribution.

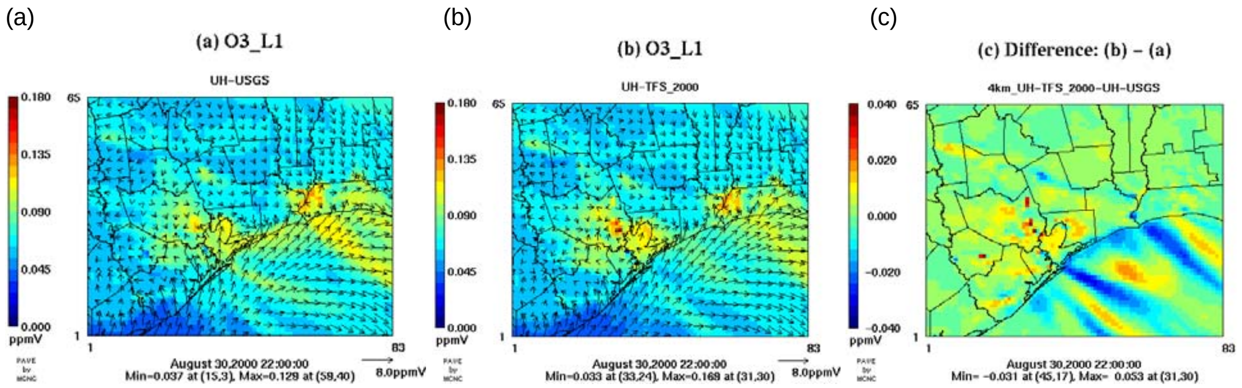

Figure 8. Same as figure 5 but showing O3 concentration distribution.

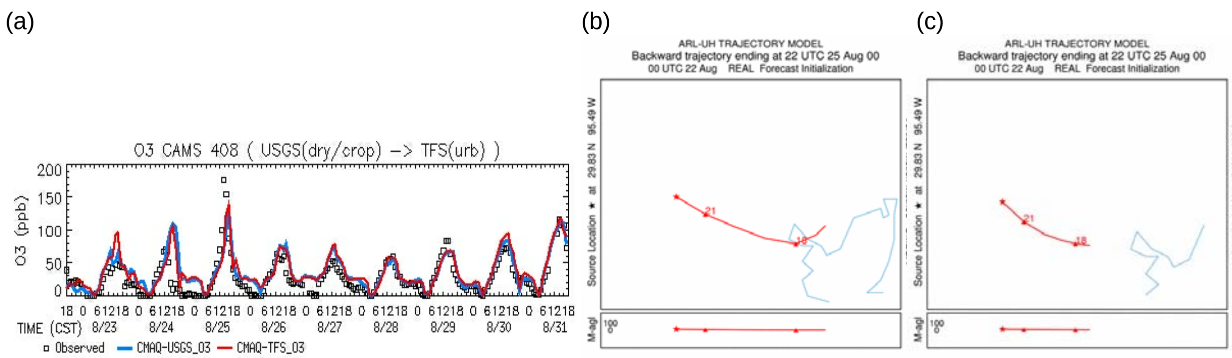

Figure 9. (a) Time-series of O3 concentration at CAMS site 408. (Square mark: observation, blue and red solid line are O3 concentration from CMAQ-USGS and CMAQ-TFS simulation respectively). Panels (b) and (c) are 6-hr backward trajectory from MM5-USGS and MM5-TFS simulation respectively at UTC2200, Aug. 25th.

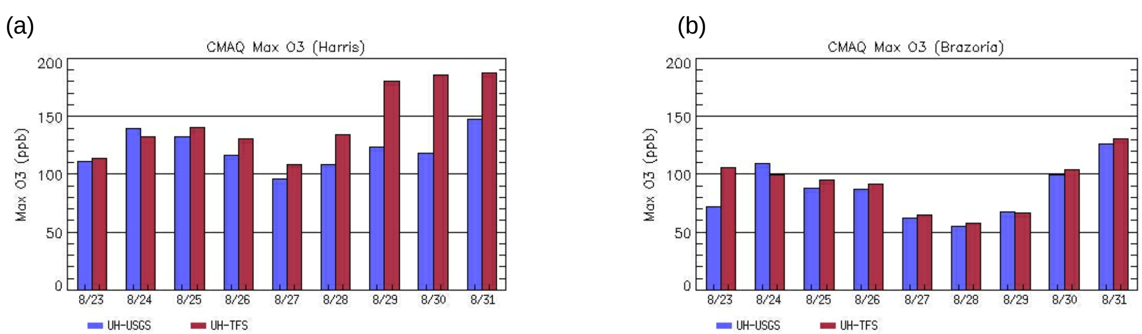

Figure 10. Comparison of maximum O3 concentration between CMAQ-USGS (blue color) and CMAQ-TFS (red color) simulations during TexAQS2000 episode for (a) Harris county and (b) Brazoria county.