Fine scale meteorological modeling of the Houston-Galveston-Brazoria ozone non-attainment area to improve air quality simulations

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Contents

- Land use and land cover *(LULC)* input data
  --- meteorological modeling
  --- air quality simulation
- Current shortcomings of the model setup
- Conclusion/Future work/Questions
Currently, MM5 uses USGS 25-category data is roughly at 1-km resolution and outdated (1990).

When dominant LU data is used, Houston metropolitan area is classified as the complete urban LULC type.

However, the recent LULC map from the Texas Forest Service shows that at least 20% of the area is covered with trees and vegetation.

MM5 over-predicts daytime temperatures in Houston downtown
How to fix daytime temperature bias?

- Canopy water ($W_c$) is added to urban area to account for the vegetation evaporation processes in Houston downtown area.

\[
\frac{\partial W_c}{\partial t} = \sigma_f P - D - E_c \quad \text{(Chen, 2001)}
\]

\[
\frac{\partial W_c}{\partial t} = \sigma_f P - D - E_c + E_u
\]

$E_u = 3 \times 10^{-6}$ (mm s$^{-1}$)
Texas Forest Service (TFS) has generated LU/LC datasets for the Houston areas (GEM, 2003).

- 30 meter resolution LANDSAT satellite imagery
Objectives

- To understand changes of transport, mixing and thermo characteristics due to use of different land use data.
- Changes of meteorological fields on air quality simulation
Configuration of Meteorological Modeling

• MM5 released version 3.6.0
• Grell cumulus at 108, 36, 12 km; no cumulus scheme at 4km
• Dudhia simple ice microphysics
• First guess and boundary conditions are from the NCEP Eta model
• Analysis nudging of wind, temperature and mixing ration for d1, d2, d3
• OBS nudging (wind vector) in d4 (Nielsen-Gammon)
• RRTM radiation scheme
• **MRF PBL** Parameterization
• **NOAH LSM**
### Land Use Table

<table>
<thead>
<tr>
<th>LAUNCHAT</th>
<th>Corresponding USGS 25-category</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 'bare_flds_barren'</td>
<td>Barren or Sparsely Vegetated' (19)</td>
</tr>
<tr>
<td>2 forest_broadleaf</td>
<td>Deciduous Broadleaf Forest' (11)</td>
</tr>
<tr>
<td>3 'forest_coniferou'</td>
<td>Evergreen Needleleaf Forest' (14)</td>
</tr>
<tr>
<td>4 'forest_mixed'</td>
<td>Mixed Forest' (15)</td>
</tr>
<tr>
<td>5 'grass_range'</td>
<td>Grassland' (7)</td>
</tr>
<tr>
<td>6 impervious</td>
<td>Urban and Built-Up Land' (1)</td>
</tr>
<tr>
<td>8 water'</td>
<td>Water Bodies' (16)</td>
</tr>
<tr>
<td>9 residential</td>
<td>residential' (newly defined)</td>
</tr>
<tr>
<td>10 residential forests</td>
<td>residential forests (newly defined)</td>
</tr>
</tbody>
</table>

Land surface parameters in the LSM where roughness length ($Z_o$) is in cm, minimal stomatal resistance ($R_{cmin}$) is in s m$^{-1}$, $R_{g}$ is the visible solar flux, and $H_s$ is a parameter for calculating vapor pressure.

<table>
<thead>
<tr>
<th>Land Use Type</th>
<th>Albedo</th>
<th>$Z_o$ (cm)</th>
<th>Emissivity</th>
<th>$R_{cmin}$</th>
<th>$R_g$</th>
<th>$H_s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Urban</td>
<td>0.18</td>
<td>50</td>
<td>0.88</td>
<td>200</td>
<td>999</td>
<td>999</td>
</tr>
<tr>
<td>2) Grass</td>
<td>0.19</td>
<td>12</td>
<td>0.985</td>
<td>40</td>
<td>100</td>
<td>36.35</td>
</tr>
<tr>
<td>3) Mixed Forest</td>
<td>0.13</td>
<td>50</td>
<td>0.94</td>
<td>125</td>
<td>30</td>
<td>47.35</td>
</tr>
<tr>
<td>4) Residential</td>
<td>0.18</td>
<td>30</td>
<td>0.94</td>
<td>40</td>
<td>100</td>
<td>36.35</td>
</tr>
<tr>
<td>5) Residential Forest</td>
<td>0.13</td>
<td>40</td>
<td>0.95</td>
<td>125</td>
<td>30</td>
<td>47.35</td>
</tr>
</tbody>
</table>
Emission/CMAQ setup

- **Texas emission inventory** including **HRVOC** for imputation were processed through the EPS2 (Emissions Preprocessing System Version 2) system.

- The emissions were applied with the plume-rise using MM5-MCIP data.

- GloBEIS3 is used for **Biogenic emissions**

- Emission input are the same for CMAQ simulation

  *(The emission data is prepared by Dr. Soontae Kim)*

- CMAQ version 4.3 was used for air quality modeling.

  *(CB4 chemical mechanism)*
Net: net radiation
Shf: Sensible heat flux
Lhf: Latent heat flux
Grnf: Ground heat flux
Surface site: Channel View

USGS: urban  TFS: residential

- TEMP
- WS
- WD
• High $O_3$ plumes are originated in Deer Park (site 139).
• Daily maximum $[O_3]$ at 194 ppb was recorded at Crawford site (407) at CST 1300, wind condition is stagnant

August 25

White color sites : $[O_3] > 120$ ppb
Gray color sites : $[O_3] > 150$ ppb
Dark gray color sites : $[O_3] > 180$ ppb
August 25
August 30

High \([O_3]\) at 169 ppb level was recorded at La Porte (608) at CST 1400 then rising to the 199 ppb level at CST 1600.

Baytown (607) also reported the maximum \(O_3\) concentration at 155 ppb at CST 1700.

Atmospheric condition was dry with high temperature (>40 degree)
Dominate by strong south flow

Horizontal Wind

Circulation vector & Vertical wind speed (contour)
Dominate by strong south flow

1800 CST Aug. 27th, 2000

(a) USGS

(b) TFS

August 27, 2000 18:00:00 (CST)
Min = 1 at (33,21), Max = 18 at (32,29)

6°C

August 27, 2000 18:00:00 (CST)
Min = 1 at (38,20), Max = 23 at (25,34)

6°C
1600 CST Aug. 30th, 2000

Sea Breeze Flow

(a) USGS

(b) TFS
RMSE, mean difference and R-square value for surface temperature and wind speed based on hourly value of 41 CAMS stations in the HGB area on 25, 27 and 30 of August.

<table>
<thead>
<tr>
<th>Date</th>
<th>Variables</th>
<th>Number of Data</th>
<th>Statistics</th>
<th>MM5-USGS</th>
<th>MM5-TFS</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mean Diff</td>
<td>0.292</td>
<td>0.579</td>
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<td></td>
<td></td>
<td>RMSE</td>
<td>1.543</td>
<td>1.525</td>
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<tr>
<td>0825</td>
<td>Temperature</td>
<td>525</td>
<td>R-square</td>
<td>0.990</td>
<td>0.991</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Mean Diff</td>
<td>0.053</td>
<td>0.016</td>
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<td>RMSE</td>
<td>0.940</td>
<td>0.880</td>
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<td></td>
<td>R-square</td>
<td>0.619</td>
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<tr>
<td>0827</td>
<td>Temperature</td>
<td>550</td>
<td>Mean Diff</td>
<td>-0.745</td>
<td>-0.473</td>
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<tr>
<td></td>
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<td></td>
<td>RMSE</td>
<td>1.400</td>
<td>1.202</td>
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<tr>
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<td></td>
<td>R-square</td>
<td>0.993</td>
<td>0.994</td>
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<tr>
<td></td>
<td>Wind Speed</td>
<td>496</td>
<td>Mean Diff</td>
<td>0.456</td>
<td>0.310</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>RMSE</td>
<td>1.059</td>
<td>0.975</td>
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<td></td>
<td></td>
<td>R-square</td>
<td>0.701</td>
<td>0.715</td>
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<tr>
<td>0830</td>
<td>Temperature</td>
<td>549</td>
<td>Mean Diff</td>
<td>0.083</td>
<td>0.407</td>
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<tr>
<td></td>
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<td></td>
<td>RMSE</td>
<td>1.536</td>
<td>1.480</td>
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<td></td>
<td></td>
<td>R-square</td>
<td>0.990</td>
<td>0.992</td>
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<tr>
<td></td>
<td>Wind Speed</td>
<td>549</td>
<td>Mean Diff</td>
<td>0.432</td>
<td>0.341</td>
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<td></td>
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<td>RMSE</td>
<td>1.083</td>
<td>1.055</td>
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<td></td>
<td></td>
<td></td>
<td>R-square</td>
<td>0.458</td>
<td>0.460</td>
</tr>
</tbody>
</table>
PBL
LULC differences on simulated PBL height

USGS

TFS

1600 CST
Aug. 30th, 2000

PBL ht

Ship Channel
Application to Houston’s air pollution problem

- Houston has serious air pollution problems
- Ship Channel has very complicated land use type (urban, residential and water body)
Tracer Experiment (Simulation w/o chemistry)

VOC (tons/day)
- tx_negu_pa_00
- VOC_DY
  - 0.00 - 0.10
  - 0.10 - 0.50
  - 0.50 - 1.00
  - 1.00 - 2.00
  - 2.00 -

ETH (Kmole/d)
- 0 - 1
- 1 - 10
- 10 - 50
- 50 - 100
- 100 -

USGS
Row 30 ETHa

TFS
Row 30 ETHa

Row 30 ETHb–ETHa

TFS–USGS
Tracer Experiment (Simulation w/o chemistry)

- NO concentrations are high over the vertical cells.
- NO emitter (stack) is tall enough to penetrate the PBL.

**NO emissions**

**USGS**
Row 30  NOa

**TFS**
Row 30  NOa

**USGS-NOa**

**TFS-NOa**

**TFS-USGS**
Daily Maximum O₃ concentration

- Ship Channel
- Baryland Park
- Parrish power plant
- Baytown

Transport, mixing??

Mixing
Shortcomings of current simulation

Over-prediction of nighttime $O_3$

Nighttime high wind bias
Nighttime high wind bias of MM5 prediction

1. Inaccurate description of regional surface temperature distribution in the Gulf Coast area due to the use of seasonal sea surface temperature (SST).

2. Resolution of the vertical layers

3. Flux-profile functions is limited under very stable boundary condition

   --- This summer’s TexAQS II experiment will provide some atmospheric boundary layer measurements to supplement data for model parameterization improvement and performance evaluation

   --- calibrate parameters used in land-surface modeling, surface similarity relations, and PBL mixing algorithms

   --- improve MM5 PBL parameterizations for coastal and urban environment
Soil parameterization for “Clay” soil type

This formation tends to overestimate (underestimate) $K_t$ during wet (dry) periods (Peters-Lidard et al., 1998).

$$K_t (\theta) = \begin{cases} 420 \exp[-(2.7 + P_f)] & P_f \leq 5.1 \\ 0.1744, & P_f > 5.1 \end{cases}$$

$$P_f = \log\left[\frac{\theta_s}{\theta}\right]^b$$

$\theta_s$: maximum soil moisture

$\psi_s$: saturated soil potential

$C(\theta) \frac{\partial T}{\partial t} = \frac{\partial}{\partial z} \left[ K_t (\theta) \frac{\partial T}{\partial z} \right]$
Unrealistic Surface Temperature High Bias

1. Utilize the University of Texas Center for Space Research (UTCSR) LULC database that can resolve the detailed surface features for a large area

2. Modify the current code structure of Noah LSM to take into account of the fractional land use, as is used in the MM5 PX LSM

(Texas vegetation data doesn’t follow BELD3 convention)
Conclusion

- USGS recognizes Houston as a complete impervious surface structure leading to “over-prediction” of daytime temperature
- With TFS-LULC data, thermo characteristics is better resolved.
- Changes of LULC data modify local wind transport especially under weak synoptic forcing, local circulation is greatly impacted by land surface features.
- Ship Channel was under influence of urban, residential and water body land use type. Utilization of TFS-LULC data which predicted the area to be stable with shallow PBL height would greatly impact air quality prediction.
- Higher ozone concentrations were observed when \textit{PBL heights is shallower, photochemical reactivity is higher (urban area) and stagnant wind condition}
- Simulation with MM5-TFS produced more precursors (NO, Ethylene) near Ship Channel emission source area
- CMAQ simulation with improved meteorological fields (MM5-TFS) successfully captures maximum O3 concentration
Future work and Questions

- We will continue examining model setup to improve our current HGA meteorological simulation.

Thanks
- Temperature
- Wind Speed
- Wind Direction
- $\text{O}_3$
- CO