Utilization of Satellite Measurements at Various Stages of Atmospheric Modeling to Improve Air Quality Simulations

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Objectives

- Present examples of utilizing satellite data for improving “inputs” for air quality modeling
  - Meteorological modeling: use satellite derived high-resolution land use/land cover data for improving surface exchange processes in MM5 (better dynamics input)
  - Emissions modeling: use of the satellite-derived high resolution vegetation data and compare biogenic emissions estimates (more accurate emissions input)
  - Air quality modeling: data assimilation of total ozone column in regional modeling (improved lateral & top BCs)
Methods

- Conduct meteorological, emissions, and air quality sensitivity modeling by …
  - Processing the satellite-derived Land Use/Land Cover data for base and future years for meteorological and biogenic emissions.
  - Simulating meteorological conditions using a modified MM5 with comprehensive NOAH land surface model.
  - Estimating biogenic emissions with leaf biomass for new satellite-derived LULC classes.
  - Link satellite-derived ozone data from global chemistry model (RAQMS) for regional air quality modeling
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 in the HGA 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)
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. (GEM, 2003)
A supervised classification process using image processing software was employed to define the classes described below:

- **Land Use**: forest, range, agriculture, urban/developed
- **Land Cover**: forest composition (coniferous, broadleaf, mixed), grass, wet land, water, barren (e.g., beach, bare soil), impervious (roads, parking lots, buildings)
To better represent surface-air exchange of momentum, moisture, and heat, we need to have high quality LULC data.

High quality LULC data improves surface energy balance and thus better characterization of PBL mixing and dynamics.

MM5 with the modified NOAH land surface model (Cheng et al., 2003) was used to improve meteorological input. (cf. Direct assimilation of satellite observed ground temperature – McNider, UAH)
Temp MM5 w/ Better LULC (AQF1) R : 0.6679, err : 2.0202
w/ original LUL (AQF2) R: 0.6562, err : 2.0415

Correlation coefficient (R),

\[
r = \frac{\sum_{i=1}^{N} (M_i - \bar{M})(O_i - \bar{O})}{\left[ \sum_{i=1}^{N} (M_i - \bar{M})^2 \sum_{i=1}^{N} (O_i - \bar{O})^2 \right]^{1/2}}
\]

Gross Mean Absolute Error (G_ERR)

Summary of Forecasting Simulations
June – October, 2005
Wind Speed

WS w/ better LULC  R: 0.2272, err : 1.6862
w/ original LULC  R : 0.1865, err : 1.7459

Ozone

Error point: Daily sum of absolute ozone conc. differences between obs. & model

Use of satellite-derived high-resolution LULC in MM 5
improves ozone forecasting!
Biogenic emissions

- The GloBEIS version 3.1 (http://www.globeis.com/) (Guenther et al., 1998; Yarwood, 1999 & 2002) was used.

- The internal database was revised to couple with the TFS LULC data and leaf mass density (LMD) data prepared for HGA.

- Meteorology inputs for GloBEIS3
  - Used the same TCEQ’s photo synthetically active radiation (PASR) estimated from GOES satellite data
  - Used the canopy temperature from MM5 simulations with TFS LULC.
TCEQ Bio.
LU/LC (Wiedinmyer et al., 2001)

TFS LANDSAT based Land Cover
Effects of using different LU/LC data
Difference –
TCEQ-bio LU/LC vs. TFS LANDSAT LC

at least consistent with surface–air exchange spatial distribution patterns in MM5
Base case O3 & Difference between LANSAT LC & TCEQ Biogenic emissions
Chemical data assimilation of satellite observation for regional air quality modeling

- Use global scale tropospheric chemistry model with satellite data assimilated to improve lateral & top BCs

  Link GEOS–CHEM or RAQMS → CMAQ

- Assimilate satellite observations directly in CMAQ
Spatial/Time resolution Issue : Global and Regional CTM

Model used in this study : RAQMS and CMAQ

RAQMS (NASA Langley Research Center and University of Wisconsin)
CMAQ (U.S. EPA)

RAQMS : Global CTM
Meteorology : U. of Wisconsin
Chemical Mech. : NASA LaRC

CMAQ : Regional CTM
Meteorology : MM5, WRF/EM, ETA
Chemical Mech. : CB4, SAPRC, RADM
RAQMS Satellite Data Assimilation

[Pierce et. al., 2004, NCEP Talk]

RAQMS uses the Statistical Digital Filter (SFD) [Stobie, 2000] (an Optimal Interpolation approach) and online chemical predictions, to evaluate the feasibility of assimilating trajectory mapped solar occultation and TOMS total column measurements.

**Satellite data used in RAQMS SOS99 O$_3$ Assimilation**

- Trajectory mapped Solar Occultation limb measurements:
- Solar Backscatter column measurements

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**Total Ozone Mapping Spectrometer**

Code 916: Atmospheric Chemistry and Dynamics Branch
Trajectory mapped solar occultation measurements constrain stratospheric $O_3$ assimilation. Mass weighted column ozone analysis increment (TOMS-background) provides constraint on tropospheric column.
CMAQ Satellite Data Assimilation – example

EPA
- MM5 run
- CMAQ v4.3 control run

NASA/UW
- RAQMS run
- Satellite data (GOES)
- SDF package

UH: Development of CMAQ Process
1. Linking tool between RAQMS/CMAQ
2. Modification of CMAQ for Satellite Data Assimilation

Evaluation: Southern Oxidant Study (SOS-99) Obs.
Evaluation

– CMAQ/Profile Results
– CMAQ/RAQMS Results

by using SFC and O3 radiosonde obs.
(SOS -- June 15-July 14, 1999)
Results: Difference of Spatial distribution at each level

Averaged $O_3$ for (FACMS B.C.) – $O_3$ (Predefined B.C.) (ppbV)
$\sigma=0.150$ ; [Jun. 15 – Jul. 14, 1999]

Averaged $O_3$ for (FACMS B.C.) – $O_3$ (Predefined B.C.) (ppbV)
$\sigma=0.350$ ; [Jun. 15 – Jul. 14, 1999]

Averaged $O_3$ for (FACMS B.C.) – $O_3$ (Predefined B.C.) (ppbV)
$\sigma=0.650$ ; [Jun. 15 – Jul. 14, 1999]

Averaged $O_3$ for (FACMS B.C.) – $O_3$ (Predefined B.C.) (ppbV)
$\sigma=0.998$ ; [Jun. 15 – Jul. 14, 1999]
Results: Evaluation for Vertical Sounding

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<th>LON.</th>
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Direct assimilation of satellite data in regional modeling

CMAQ/SDF with GOES Ozone

**GOES**
Ozone File
(t=T1)

**SDF**
- porting onto Linux platform
- read GOES & CMAQ con.
- calculate Error Field
- modify CMAQ Ozone con.

**CMAQ**
- Simulated Ozone Con. (t=T1)
- Modified Ozone Con. (t=T1)
- Integration (t=T1+dt)
Assimilation of satellite column ozone data for regional air quality modeling: CMAQ/SDF

RAQMS/GOES
Data assimilation method
From Brad Pierce

Satellite (GOES data)

Observation (TOC, 1 hr)

Forecasting (TOC, 1 hr)

Merging

OmF (Observation-Forecasting)

SDF (Statistical Digital Filter)
: OI (Optimal Interpolation)

Analysis (1 hr)

RAQMS
O_3 Forecasting (6 hr)
: For upper level (>100 hPa)

CMAQ
O_3 Forecasting (1 hr)
: For lower level (<100 hPa)
Observation (TOC, 1 hr)

Averaged Observation (GOES data) of Total O₃ Column (DU)

First guess (TOC, 1hr)

Averaged Total O₃ Column from CMAQ and RAQS (DU)

OmF (TOC, 1hr)
(Observation-Forecasting)
On-going work

(1) Utilization of satellite-derived sea-surface temperature in MM5 modeling to improve meteorological inputs

(2) Inclusion of satellite-derived fire emissions to improve emissions inputs (NESDIS, ARL, NCAR – C. Wiedinmyer, Harvard – J. Logan & D. Jacob)

(3) CMAQ–4D VAR (in collaboration with Sandu (VT), Carmichael (U. Iowa), HARC, EPA, CalTech)

Acknowledgement

NASA: Brad Pierce, Al-Assad, Doreen Neil

EPA: Jim Szykman, Alice Gilliland, Ken Schere

SAIC: Fred Vukovich,

University of Wisconsin, USDA, Texas Forest Service, TCEQ, GEM