Recent developments and plans for WRF-CMAQ modeling

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Outline

• WRF V3
  – PX LSM
  – ACM2
• MCIP updates
• NLCD
• 2-way WRF-CMAQ
T-2m bias relative to analysis for January 2006

T-2m mean absolute error relative to analysis for January 2006
The Asymmetric Convective Model
Version 2

- The ACM2 is a combined transient and eddy diffusion scheme
- The ACM2 provides consistent transport for all meteorology and chemistry species
- The ACM2 has been implemented in:
  - MM5 (not in the NCAR release)
  - WRF-ARW v3.0
  - The Community Multiscale Air Quality (CMAQ) model
  - The new WRF-CMAQ “online” coupled system
- Details in Pleim (2007 JAMC 46, 1383-1395)
ACM2 Evaluation

• Single column experiments:
  – Dry LES convection (Keith Ayotte)
  – GABLS2 (CASES-99), GABLS3 (Cabauw)

• Mesoscale meteorology
  – MM5 – 12 km grid sizes for eastern US, summer 2004
  – WRF - 12 km grid sizes for eastern US, summer-fall 2006, and January 2006

• CMAQ - 12 km grid sizes for eastern US, summer-fall 2006 (TexAQS II)
PBL Heights from TexAQS II

• PBL heights derived from 10 radar wind profilers in Texas by Jim Wilczak and Laura Bianco NOAA/ESRL

• Statistics of observations and model by hour of the day for August 1 – October 4
  – Median values with error bars that represent the 25th and 75th percentiles
TexAQS 2004 wind profiler network
PBL Height (inland sites)

Moody

Longview

Cleburne

New Braunfels
PBL Height (near Houston)
PBL Height (near coast)
NOAA P-3 aircraft flight paths
Sept. 11 – Oct. 12, 2006
Layer average P-3 measurements vs CMAQ

Vertical structure of chemical species similar near top of daytime BL
Example of vertical profiles 80 km downwind of Dallas, 9/25/06
P3 vs AQ forecast models

09/25/06
80 km south of Dallas

Ascent 19:01:02-19:05:34
(UTC)

Courtesy of Stu McKeen (NOAA/ESRL)
Example of vertical profiles
80 km downwind of Dallas, 9/25/06

Severe overprediction of CMAQ’s mixing depth

09/25/06
80 km south of Dallas

Ascent 19:01:02-19:05:34 (UTC)

Courtesy of Stu McKeen (NOAA/ESRL)
Example of vertical profiles
80 km downwind of Dallas, 9/25/06

Too much gradient for WRFchem
New runs of WRF-ARW v3 – CMAQv4.7 (9/25/2006 19UTC)
Later on the same fight (20 UTC) at GMD tower (Moody TX)
P3 flight on 9/26/2006 18 UTC spiral about 60 km west of Houston
P3 flight on 9/26/2006 18 UTC spiral about 60 km west of Houston

![Diagram](image)

**Left Panel:**
- Red line: P3 - NOy
- Blue line: WRF-ARW

**Right Panel:**
- Red line: P3 - O3
- Blue line: CMAQ
P3 profile 9/13 near GMD tower
22 UTC
P3 profile 9/13 near GMD tower
22 UTC
Houston Ozonesonde
August 31, 2006 – 1829Z

Potential Temperature (K)

Qv(g/kg)
PBL

- PBL heights compare well with daytime observations from radar wind profilers.
- The ACM2 in both the WRF and CMAQ models shows consistent vertical profile structure between meteorological and chemical species.
- Comparisons to aircraft spirals show realistic vertical structure of meteorological and chemical species.
MCIPv3.4
(to be released in September 2008)

- Added processing capability for GOES-East satellite analyses for cloud parameters used for photolysis in CMAQ.
- Dry deposition
  - Changed parameterization for surface resistance of gasses to water bodies
  - Added an exception for elemental mercury deposition to wet soil surfaces
  - Added dry deposition velocities for five air toxic species.
- Added 2-m mixing ratio (Q2) to the METCRO2D output.
- Added turbulent kinetic energy (TKE or TKEF) to the METCRO3D output, if it is available from MM5 or WRF.
- Added nudging coefficients to metadata and earth radius assumed in MCIP to user input and to metadata
MCIPv3.4 (cont)

- **WRF Only:**
  - Added preliminary support for the urban canopy model.
  - Changed settings for domain parameters in GRIDDESC and M3IO headers for Lambert conformal projection and polar stereographic projection to be compatible with M3IO.
  - Allow skin temperature to be filled by top-layer soil temperature, if skin temperature is unavailable in output.
  - Expand tables of LU parameters to include 33 USGS land use categories.
  - Made accommodations for the NOAH LSM.
  - Changed read of vegetation fraction to preferentially use VEGF_PX rather than VEGFRA for Pleim-Xiu land-surface model.
NLCD

• National Land Cover Database
  – Higher res – 30 m
  – More recent – base 2001 updating to 2006
  – More accurate
  – Additional information – Canopy cover, impervious

• Developing processing tools for combined NLCD for US with Modis LU (1 km res) for outside US

• Revise PX LSM and M3dry LU related parameters
WRF12km Grids, NLCD, and MODIS
Eastport, ME and Fairhaven, CAN
NLCD Canopy Percent for Small WRF12km Domain

Legend
CANOPY_Layer
<VALUE>
0
0 - 10
10.00000001 - 20
20.00000001 - 30
30.00000001 - 40
40.00000001 - 50
50.00000001 - 60
60.00000001 - 80
80.00000001 - 96.25573834
NLCD Deciduous Forest for Small WRF12km Domain

Legend

LANDUSEF_Layer6

<VALUE>

- 0
- 0 - 10
- 10.00000001 - 20
- 20.00000001 - 30
- 30.00000001 - 50
- 50.00000001 - 60
- 60.00000001 - 70
- 70.00000001 - 80
- 80.00000001 - 96.05750275
Rationale for 2-way Met/AQ modeling

• Aerosol concentration, size distribution, and composition can be used to modulate direct radiative forcing in the meteorology model

• Aerosol composition and size distribution can be used in cloud microphysics (indirect forcing)

• Met-Chem data exchange can be as frequent as the model time steps (~ 1 min, depending on grid resolution)

  – *Note that such high rates of data exchange are not practical using I/O disk files*
WRF/CMAQ Development

- Modified WRF for air quality applications.
  - Newtonian Nudging Four Dimensional Data Assimilation system to WRF
  - Pleim-Xiu land surface model (PX LSM)
  - Asymmetric Convective Model version 2 (ACM2)
- Modified CMAQ to include met dependent processes
  - Biogenic emissions,
  - Point source plume rise,
  - Dry deposition velocity
    - Bi-directional surface flux modeling for ammonia
- Coupling WRF and CMAQ into single executable
Design of WRF/CMAQ system

**WRF**
- Solve.F
  - physics drivers
  - radiation
  - microphysics
  - dynamics
- aq_prep
- CMAQ (time, Δt)
- aq_post

**CMAQ**
- vdiff
- biogenic emis
- plume rise
- surface flux
- hadv
- zadv
- hdiff
- cldproc
- chem
- aero

Flow:
- emission data
- initial conditions
- boundary conditions
Features

• Flexible time stepping
  – CMAQ can be called every WRF timestep or at any user defined multiple
  – Met buffer file always holds two time steps of data allowing interpolation

• Simple switching of buffer file to disk file allows identical off-line simulation (without feedback)

• Direct aerosol feedback to WRF CAM radiation model
Radiative effects of aerosols

Column integrated AOD at 280 nm

Sulfate aerosol concentration - $\mu$g/m$^3$

August 2, 2006 20:00:00
Min: 0.000 at (45,104), Max: 0.717 at (243,133)

August 2, 2006 20:00:00
Min: 0.000 at (99,99), Max: 16.942 at (237,129)
Direct aerosol feedback effects

No feedback – feedback

Layer 1 SWDOWNe

Layer 1 T2e

August 2, 2006 20:00:00
Min = -782.043 at (39, 119), Max = 774.963 at (33, 64)

August 2, 2006 20:00:00
Min = -3.522 at (34, 110), Max = 3.081 at (125, 237)
Next steps

• Further testing of coupled WRF/CMAQ for summer 2006 at 12 km grid resolution
  – Assess longer term effects of direct feedback
  – Look for semi-direct effect
• Develop indirect feedback of aerosol on microphysics
• Implement direct effects on LW
• Update to WRF 3.0 and CMAQ 4.7