THE MODELS-3 COMMUNITY MULTI-SCALE AIR QUALITY (CMAQ) MODEL: Linking with NWS Eta Model for Air Quality Forecasting

Kenneth Schere*
Atmospheric Sciences Modeling Division
NOAA - Air Resources Laboratory
Research Triangle Park, NC

* On assignment to the National Exposure Research Laboratory, U.S. EPA.

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Although this work was reviewed by EPA and approved for publication, it may not necessarily reflect official Agency policy.
National Air Quality Forecasting

Background

- Congressional interest
- H.R. 4 Energy Policy Act of 2002 (Senate Amendment)
  S. 517, SA 1383, Forecasts and Warnings: “The Secretary of Commerce, through the Administrator of the National Oceanic and Atmospheric Administration, shall, in order of priority as listed in section (c) establish a program to provide operational air quality forecasts and warnings for specific regions of the United States…”
- Constituent interest
  - AQ managers, public health officials, private weather sector partners urge NOAA to provide AQ forecasts
- Science is mature
  - Ozone forecast models demonstrated in lab -- others in development
  - Other nations (e.g., Canada, Australia, Spain) have existing AQ forecast capability
- NOAA-EPA Agreements
  - On May 6, 2003, DOC Deputy Secretary and EPA Administrator signed MOA on AQ forecasting
PARTNERSHIPS IN AIR QUALITY FORECASTING

NOAA
- Develop and evaluate tools for national/state/local air quality forecasting
- Provide operational air quality models and forecast pollutant concentration fields with national coverage

EPA
- Maintain current national emissions inventory
- Maintain national air quality monitoring databases
- Disseminate/interpret national air quality forecast information - AQI and links to public health

STATES / LOCALS
- Provide state/local emissions data
- Provide state/local air quality monitoring data
- Provide local AQI forecasts/warnings

PUBLIC and COMMERCIAL SECTORS
CMAQ Assessment Model → CMAQ Forecast Model

- Increase computational speed
  - Decrease generality and flexibility
- Customize system architecture to NCEP IBM-SP
- Post-process Eta output for CMAQ input
- Streamline emissions processing
- Test new mass adjustment schemes in conjunction with Eta model adaptation
- Develop procedures for initial and boundary conditions for real-time runs
Computational Efficiencies

• Develop architecture where I/O overlaps computation
  – One processor handles output to disk
  – Many processors perform chemistry-transport kernel (CTK) computations
  – Synchronization mechanism - MPI communication

• Model runs in mode similar to Multiple Instruction-Multiple Data (MIMD)
• Domain decomposition
• New mass-adjustment scheme in CMAQ
  – Diagnoses vertical velocities to satisfy mass continuity
  – Based on work of R. Yamartino
• Other efficiencies
  – Smaller gas-phase mechanism (CB4)
  – Dropped transport of fast-reacting radical species
  – Disabled aerosols (for initial forecast version of CMAQ)
  – Eliminate some indirect addressing
  – Reordered some array arguments for cache efficiencies
Meteorological Processing

• Eta Model – 60 vertical layers; stepped-mountain vertical coordinate; Arakawa-E staggered grid; rotated latitude/longitude map; North America continental coverage

• CMAQ Model – 22 vertical layers; sigma-P vertical coordinate; Arakawa-C staggered grid; Lambert-conformal map; Northeastern U.S. coverage
• Interpolations needed in linkage
• Eta $\rightarrow$ Eta-Post $\rightarrow$ Product Generator $\rightarrow$ PREMAQ $\rightarrow$ CMAQ
• PREMAQ Processor
  – Equivalent to MCIP processor in standard CMAQ model system
AQ forecast modeling – emissions processing

- **Approach:** modify and streamline existing emission inventories and emission modeling systems used for EPA air quality analysis

- **Overall philosophy:** Simulate the complexities from significant source categories, and simplify processing when possible. Key complexities are in biogenic, mobile, and major power plants.
More efficient emissions processing:

• Biogenic emissions
  – Streamline BEIS3 (hardwire the chemical speciation)
  – Identify and use appropriate met variables from ETA
  – Use vegetation fraction files to drive leaf biomass density

• Mobile emissions
  – Develop pre-calculated gridded emissions [hourly, day-of-week]
  – Develop simple temperature regressions to apply to pre-calculated emissions
• Major fossil-fuel power plants
  – Plume rise – meteorologically dependent
  – Include effects of current emissions control programs (SO\textsubscript{x}, NO\textsubscript{x})
  – Try to link with daily forecasts of power generation; test and apply relationships and compare with CEM data (in future plans)
Initial and Boundary Conditions

• ICs
  – Model is initialized with concentrations from previous run (continuity with earlier run is maintained) – self-cycling

• BCs
  – 2003 season – lateral boundaries set to continental or maritime background profiles for all species; sfc ozone ~ 50 ppb
  – 2004 season – same, except ozone profiles obtained dynamically from Global Forecast Model/ Data Assimilation system
Current CMAQ Modeling System

MM5 – Meteorological Model

Met-Chem Interface Processor

SMOKE - Emissions Model

CMAQ Air Quality Model

CMAQ Forecast System

NCEP Mesoscale Meteorological Model (Eta)

PREMAQ Processor - Emissions, Met. data prep

CMAQ AQ Model - Chemical-Transport Computations
• Schedule
  – July-Sept. 2003 – Initial system tests at NOAA/NCEP during 2003 ozone season
    • Northeast US domain
    • 12km grid cells
    • 1-day forecast – $O_3$
  – October 2003-May 2004 – Refine system for NCEP operations
  – May 2004 – Begin operational real time test and evaluations at NOAA/NCEP
  – September 2004 – Initial operational Eta-CMAQ forecast system for Northeast US
AQF CMAQ Model Northeast Domain
Anticipated Production Cycle

• First Forecast Run

Day 0
0800 EDT

Day 0
~1000 EDT

Day 0
~1330 EDT

Eta model initialized → Eta post-processors → CMAQ preprocessor (PREMAQ) → CMAQ Model (48-h run) → Forecast O3 concentration fields (1-hr, 8-hr averages)

Model Forecast:

Day 0-8am  Day 1-8am  Day 2-8am  Day 3-8am  8pm

Eta (Met)  

{Prime forecast period}  

CMAQ (AQ)
- Second (updated) Forecast Run

<table>
<thead>
<tr>
<th>Day 1</th>
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<tr>
<td>0200 EDT</td>
<td>~0400 EDT</td>
<td>~0730 EDT</td>
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- Eta model initialized
- Eta post-processors
- CMAQ preprocessor (PREMAQ)
- CMAQ Model (30-h run)
- Forecast O3 concentration fields (1-hr, 8-hr averages)

Model Forecast:

- Eta (Met) {Prime forecast period}
- CMAQ (AQ)
Future Plans for Eta-CMAQ System

• Initial evaluation
  – August 6-16, 2002; Northeast U.S.
  – July-September 2003; Northeast U.S.

• Evaluation during 2004 Northeast field studies

• Over next 5 years:
  – Expansion of model domain to CONUS
  – Add PM2.5 simulation
  – Expansion from 1-day to 3-day forecasts
  – Transition from Eta to WRF met driver

• Move to “on-line” AQ forecast model – WRF/Chem
• Creation of CMAQ air quality forecast archive
  – Useful to EPA and states as a resource to drive urban scale SIP modeling for short- or long-term simulations
    • Meteorological data archive
    • Air quality forecast data archive
  – Developing climatologies of air quality over continental U.S.
• Analysis of CMAQ air quality forecast outputs
  – Assessing signals of emissions change on air quality
  – Evaluate NOx- and VOC-limited regions on a long-term basis
  – Couple air quality and health data to examine the inter-relationships