Recent Performance of the NOAA Air Quality Forecasting Capability and the Impact of Driving Meteorology

http://www.emc.ncep.noaa.gov/mmb/aq

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Outline

• Overview CMAQ V5 & NAM V4 upgrades
• Evaluate ozone performance of V4.7 vs 5.0.2
• Experimental: Ozone Bias Correction
• Evaluate PM performance of V4.7 vs 5.0.2
• PM Bias Correction (Exp: use of V5 analogs)
• Experimental: HYSPLIT smoke emissions tests
• NEMS Global Aerosol Capability
• Future : FV3-Chem
CMAQ V4.x weaknesses Identified

• **Overprediction of ozone in Eastern U.S. in Summer**
  – Especially along coastal cities (NYC, DC, Cleveland)
    → Update National Emission Inventory point sources to 2011 (project to 2016)
    → Evaluate NOx emissions based on OMI satellite trends (Deferred)
    → Evaluate Impact of NAM V4 and reduced SW radiation under clouds
    → Update CMAQ gas and aerosol chemistry/biogenic emissions to EPA V5.0.2

• **Underprediction of particulate matter (PM) in Summer and near wild-fires**
  → Update 10 year old USFS BlueSky smoke emission system
  → Introduce 24 h pre-analysis cycle to correct fire time mismatch with CMAQ initial time

• **Underprediction of Ozone and PM when strong fires are present outside CMAQ domain**
  → Test NGAC full aerosol predictions for CMAQ lateral boundaries (deferred)

• **Overprediction of PM during winter-time stagnation episodes (cold, stable)**
  → update emissions/chemistry as in bullet 1
Updated USFS BlueSky smoke emissions:
- The Fuel Characteristic Classification System version 2 (FCCS2) which includes a more detailed description of the fuel loadings with additional plant type categories.
- Explicit fuel load map for Alaska
- Improved fuel consumption model and fire emission production system (FEPS).

Courtesy Ho-Chun Huang, EMC
Analog Ensemble for PM$_{2.5}$ Bias Correction

- Analog metric is determined by (Monache et al. 2011)

\[
\|F_t, A_{t'}\| = \sum_{i=1}^{N_v} w_i \frac{1}{\sigma_i} \sqrt{\sum_{j=-i}^{i} (F_{i,j} - A_{i,j})^2},
\]

where $F_t$ is current NWP forecast valid at future time $t$, $A_{t'}$ is analog at past time $t'$, $N_v$ is the number of variables, $\tilde{t}$ is half the number of additional computation time, $w_i$ weight, $\sigma_{f_i}$ standard deviation.

Implementation in NAQFC
- Variables for Analog search: PM$_{2.5}$, $T_2$, WS/WD
- Ensemble members: 5
- Training period: one year

Kalman Filter: adds temporal changes

(Source: Djalalova et al., 2015)

Courtesy Jianping Huang, EMC
Resolutions Changes
- CONUS (4 km) and Alaska (6 km) nests → 3 km
- Sync AK and CONUS On-Demand Fire Weather nests → 1.5 km

Select Model Changes
- Updated microphysics → Improved stratiform precip., better anvil reflectivity, lower peak dBZs, smaller areas of light/noisy reflectivity (rain treated as drizzle), improved nest QPF bias in warm season, Reduce incoming SW Rad under clouds; reduce warm season 2-m T warm bias
- More frequent calls to physics → Physics/dynamics more in sync (e.g. improved upper air, improved nest QPF)
- Improve effect of frozen soil on transpiration and soil evaporation → Improve cold season 2-m T/Td biases
- Adjustment to convection in 12 km NAM → Improve QPF
- Modify latent heat flux treatment → Improve visibility along CA coast

Data Assimilation:
- DA cycles for 3 km CONUS and AK nests → Much less ‘spin-up’ time
- Use of Lightning and Radar Reflectivity-derived temperature tendencies in initialization
  - Improved short-term forecasts of storms at 3 km
  - Improved 00-12 hr QPF
- New satellite radiances, satellite winds → Improved Initial Conditions

Courtesy Eric Rogers, EMC
NAM March 21, 2017 Upgrade

Mean 2-M Temp vs. sfc obs (128 cycle) over the Western US for one NAM and p1l NAM forecasts from 201607190000 to 201608291200

Mean 2-M Temp vs. sfc obs (128 cycle) over the Eastern US for one NAM and p1l NAM forecasts from 201607190000 to 201608291200

2 m Temperature
July 2016 NRT CMAQ  Prod vs V5.0.2

1 h avg Diurnal Ozone

- **CMAQ V5.0.2 NAM-V4**: improvement in ozone over-prediction over the East

- **CMAQ V5.0.2 NAM-V4**: Strongest underestimate over West

- Meteorological impact nearly as large as CMAQ/Emissions upgrade
Experiments to address missed exceedences

- **No NOx Adjustment for Mobile Emissions (green line)** NAMX
  - Cross State Air Pollution Rule (CSAPR) 2011 Mobile Emission
  - Should result in increased ozone product

- **Gridded NOx Mobile emission adjustment (red line)** NAMX
  - Adjustment factor also considers fine-scale features by taking into account the 12 x 12 km grid-by-grid satellite-observed NOx to NAQFC forecasted NOx ratio

- **V5.0.2 Para**: State wide NOx adjustment using NAM
August 2016
East vs West  Ozone

No-NOX: Slight improvement during day over East
Slightly better over West late August
August 18, 2016 Day 1

- NAMx showed a great improvement over PROD;
- NAMx eliminated the four false alarms.

*Courtesy Mike Geigart, CT DEP*
• Winds coming from the bay brought the marine air inland
• The NAM NEST 3km tended to bring the MBL further inland in the northern Chesapeake bay area, especially north of Baltimore

Courtesy: Amanda Sleinkofer
Ozone Errors: July 2017
Obs vs Raw vs Bias Corrected

East: Overprediction overall but underprediction for July 10-12 exceedences
West: Continued underprediction

O3 BIAS CORRECTION:
→ Diurnal performance good, overcorrects some events (July 10-12, 18-21)
Cool, moist biases on 11th and 12th coincides with ozone underprediction
July 12, 2017 NAM-CMAQ V5 Performance

- Continued less ozone predicted for day 2
- O3 Bias correction improved over LI

Bias Corrected 8h Ozone Max: Day 2

CMAQ 8h Ozone Max: Day 1

CMAQ 8h Ozone Max: Day 2

8h Ozone Max: Day 1 Mdl-Obs
July 12, 2017 NAM-CMAQ V5 Performance

NE U.S. NAM,Nest, CMAQ 7/11/ 12Z  33 h Cloud Cover

- NAM-12 cloud cover too high and extent too broad, CMAQ less
- NAM nest captures clearing along LIS and CT better
NAM: Temps too cool over CT coast, Nest better
NE events captured albeit a bit overestimated by raw model
Underestimated in Western PA, DC day 2 made worse by BC
July NAM-CMAQ V5 Performance

- Continued less ozone predicted for day 2
- BC: Overcorrected in Sacramento & Ohio Valleys
Current issues of $PM_{2.5}$ predictions

- Significant seasonal bias
  - over-prediction in winter
  - Under/over in summer
- Sources of the bias
  - Emissions
  - Met (PBLH)
  - CMAQ chemistry
  - Deposition
  - LBCs

Over-prediction in winter is improving
Operational runs: Most sites impacted by fire smoke are severely under-predicted.
Experimental tests: Updated BlueSky and use of current day fire info.
July 29, 2016 Big Sur Fire forecast and comparison to PM measurements

Smoke Emissions
- Location
- Magnitude
- Ejection height
- Diurnal evolution
August 2017 PM Predictions

1 h avg PM BIAS  West

- WEST: Underpredict PM transitions to overprediction.
- Bias Correction w/ V5. analogs better than oper BC
  - More consistent smoke event analogs?
August 2017 PM Predictions

1 h avg PM BIAS   EAST

- East: PM overprediction
- *Bias Correction* w/ V5. analogs similar to oper BC
Aug 25-Sept 5 2017 PM Prediction

1 h avg PM: North West U.S. Fires

- Underprediction for Day 2 in general BUT:
  - Day 1 Overprediction in early morning for smoke events
    - No diurnal emissions profile used
  - Oper Bias correction performs poorly for smoke
August 29, 2017 PM Predictions

1 h avg Max PM : North West U.S. Fires

- Pyrocumulonimbus (Pyrocu) lofting of smoke
- Less PM predicted for day 2
  - CMAQ : 75% fire reduction after analysis responsible?
- PM KFAN w/ V5 analogs overcorrects
November 15, 2016

1 h Daily Max PM: South East U.S. Fires

- BC underpredicts fire events, but still closer than other runs
February 2017
East vs West PM and Bias Corrected PM

V5.0.2 (red) – Little improvement over CMAQ V4.7
East Bias Correction - corrects for strong PM overprediction
• Improved out west, but overprediction sometimes worsened over East
• Replace NOAA HMS Canadian Fire Emission with ECCC Fire Work Emissions.
• In general, some of the wildland fire locations of ECCC FireWork are different from NOAA HMS.
• Daily fire smoke PM$_{25}$ emissions of ECCC, in general, are less than that of NOAA HMS/BlueSky.
• The impact of different fire emission and diurnal emitted pattern can reach as far as the US East Coast.
• decreased performance w/ ECCC for August 2017 for concentration < 20 µg/m$^3$. Slightly better for that > 20 µg/m$^3$.
• http://www.emc.ncep.noaa.gov/mmb/hchuang/web/html/hysplit Bluesky.html
Fire behaviors difference between PROD, PARA, and PARA1 in Forecast Run

CMAQ : Forecast Runs (48 Hours; 24 Hour duration fires only)

- PROD reduces the PM$_{25}$ emission and Heat in analysis run with 75 % reduction.
- EMC PARA reduces the PM$_{25}$ emission and Heat in analysis run with 75 % reduction. (the summation of 24 hour PM$_{25}$ emissions is 25% of PROD)
- EMC PARA1 uses the PM$_{25}$ emission and Heat in analysis run without reduction. (the summation of 24 hour PM$_{25}$ emissions is the same as that of PROD)
- Comparisons in next slides

Diagnosis Date : September 11 2017. Selected fire.

Courtesy Ho-Chun Huang
Over the **night-time** hours, both PARA (b) and PARA1 (c) emitted less PM$_{2.5}$ as compared to PROD (a) near source area, (d) and (e).

Over the **day-time** hours, PARA (b) is slightly less that of PROD (a) and PARA1 (c) emitted more PM$_{2.5}$ than PROD (a) near source area, (d) and (e).

Courtesy Ho-Chun Huang
Summary

– **V5.0.2 Ozone w/ NAM V4**
  - Improvement correcting over-prediction esp along coasts
    - Long Island Sound (CT DEP analysis), Lake Erie/Michigan and Ohio Coastline
  - Improved for marginal or non-events
  - Still Missed exceedences in NE with overprediction of cloudiness
  - *Remarkable overall improvement with KFAN ozone bias correction* overcorrects for episodes in East

– **PM**
  - Large positive impact near forest fires:
    - Updated BlueSky and 24 h pre analysis run
    - Underprediction when external sources (Canadian fires) are impacting CONUS
    - Emission timing and ejection height uncertainties
  - Continued overprediction in Winter from raw predictions
  - Experimental PM bias correction w/ V5 analogs improves performance (Summer)

– **HYSPLIT V7.4**
  - Improvement for large fires with upgraded BlueSky
  - Experimental ECCC & temporal emissions produce mixed results

– **Normally Updated NAM alone improves ozone overprediction forecast**
  - Amount of incoming radiation under clouds critical
Future Emphasis

– Extend to 72 hours, update emissions to 2014 base
– Near real-time fire locations, strength, emissions
  • Canadian & external source impacts (testing)
  • Improved temporal profiles (testing) and plume rise algorithms
– NGAC full aerosol boundaries
– Unification of AQ systems
  • HYSPLIT smoke/dust \(\rightarrow\) NGAC Aerosol
  • CMAQ ozone & total PM
  • HRRR-smoke
– Bias Correction:
  • Implement Ozone Kalman Filter bias correction
  • PM: Use CMAQ V5 predictions as analogs
– Improved Evaluations
  • Use of VIIRS/GOES-16/AERONET AOD, CALIPSO aerosols
  • Evaluate Operational models for field experiments (ESRL FireX 2019, FASMEE)
Thunderstorm-resolving resolution in a unified meso-global prediction system (FV3-GFS)

1) Grid stretching (smooth variation of grid spacing)

2) 2-way nesting (Harris and Lin 2014)
   FV3 is uniquely suitable for 2-way nesting, due to the application of two-time-level Finite-Volume transport scheme

2) Optimal combination of the “stretching” and “nesting”

FV3-GFS

→ FY19 Global : 9 km L64
→ Regional: 3km nest or stand alone
→ aerosol aware microphysics/radiation option

S.J. Lin, NOAA/GFDL
BACKUPS
Web pages
CMAQ V5.0.2

- Real-time parallel runs (July 2016-Present)

- No NOx adj/NAM-X/4x-day cycling (Aug. 7-Sept 10)

- Gridpoint NOx adj/NAM-X/1x-day cycling (Aug. 1-Sept 10)

- Verification statistics (prod,para, cmaqnox11, cmaqnox)