Regional Air Quality Modeling Progress at NOAA/NWS/NCEP

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September 10, 2015
NAQFC: NMMB-CMAQ

• Update emissions to NEI base year 2011 (ARL/EMC)
• Increase vertical levels from 22 to 35 (ARL/EMC)
• Provide dust boundary conditions from NGAC (ARL/EMC)
• Test a bias correction scheme for particulate matter prediction (EMC/ESRL)
• Update of Blue Sky smoke emission system (EMC/USFS)
A flow-chart of the NMMB-CMAQ system
(new Changes as indicated by the red dashed boxes)
Current issues of PM$_{2.5}$ predictions

- Significant seasonal bias
  - over-prediction in winter
  - under-prediction in summer

- Sources of the bias
  - emissions ?
  - Met inputs like PBLH ?
  - CMAQ itself?
  - LBCs?

Over-prediction in winter is getting improvement and Under-prediction in summer is unchanged
Current issues of PM$_{2.5}$ predictions
Approaches of PM$_{2.5}$ Bias Correction

- Running-mean
- Kalman-Filter (KF) approach (Delle Monache et al., 2006)
- Analog Ensemble forecast (AnEn) (Hamill and Whitaker, 2006; Monache et al., 2013)
- Combined Analog with the Kalman-Filter (KFAS) (KF applied to standard time series of data)
- Combined Analog with the Kalman-Filter (KFAN) (applying the KF to the AN time series)

_Djulalova et al. (Atmos. Environ. 2015)_
Analog Ensemble in Probabilistic Weather Prediction

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

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

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.
Analog Ensemble for PM$_{2.5}$ Bias Correction

- Interpolate CMAQ outputs into AIRNow observational sites
- Search for similar patterns from the historical data (combining PM$_{2.5}$ with T, SR, WS/WD)
- Calculate the forecast biases at the observational sites
- Spread the forecast biases to the entire domain

*Djalalova et al. (Atmos. Environ. 2015)*
Analog Ensemble for PM$_{2.5}$ Bias Correction (cont.)

KFAN shows the best performance
Analog search variables: PM$_{2.5}$, T, SR, WD, and WS

Djalalova et al. (Atmos. Environ. 2015)
Configurations of NMMB-CMAQ runs

- **Met inputs:** NMMB 12-km (bgrd3d files)
- **Emissions:** 2005 NEI + part of 2011 NEI (without mobile sources) + Blue Sky fire/smoke emissions (no gas)
- **CMAQ:** CB05 gas-phase mechanism + Aero 4 module + 35 vertical levels
- **Lateral Boundary Conditions:** NGAC dust + 2006 GEOS/Chem simulations (for gas + others of PM\(_{2.5}\))
- **Bias Correction for PM\(_{2.5}\):** Analog Ensemble with training period of 8 weeks, 3 analog ensemble members and using PM\(_{2.5}\) + T+WD/WD as analog search variables.
Testing for winter month (Jan/2015)
Testing for winter month (cont.)

[Graphs and charts depicting data analysis for WUS and EUS regions with a focus on PM2.5 levels before and after bias correction.]
Testing for summer month (July 2015)
Testing for summer month (cont.)
A case study on July 4th
1-hr average Ozone

Jan/2015

WUS

Jul/2015

SWEST

EUS

EUS
Summary for NMMB-CMAQ

• Operational ozone predictions
  – No much change with CMAQv4.7.0
  – Over-prediction in most regions of US except for Southwestern coastal region

• Experimental PM predictions
  – positive impact from updated emissions and NGAC LBCs (dust only)
  – Better emissions from wild fire smoke
  – Significant improvement with Analog Bias Correction

• Met performance should be carefully evaluated while proceeding to address other system errors
  – Concern that we are making changes to chem/emissions that mask 1st order met errors
Future plans

• Short term (1-2 years)
  – Include NGAC real-time full aerosol in boundary conditions
  – Improve smoke emissions
    • Update Bluesky emissions
      – (forest load, consumption, spread emissions)
    • Evaluate NGAC Fire Radiative Power smoke emissions approach
    • Evaluate plume rise (additional met constraints)
  – Refine ESRL bias correction
    • KFAN
    • Parallel version
• The particulates matter (PM) generated from forest fires often severely impact the air quality and human health in the nearby and downstream areas. Wildfires occur randomly and the intensity and location of fire can change with time. It is extremely difficult to model the fire smoke particulate both in spatial and temporal scale.

• The National Weather Service uses the HYSPLIT smoke forecasting system (NWS/HYSPLIT smoke) to forecast the smoke concentration resulting from fire (next slide). It consists of the NOAA National Environmental Satellite, Data, and Information Service (NESDIS) Hazard Mapping System (HMS) fire and smoke detection system, the emission module of the US Forest Service BlueSky Smoke Modeling Framework (BlueSky), and the Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model.

• The latest update (in progress) is to incorporate the emissions module of a newer version of the BlueSky.
The Flow Chart of NWS/HYSPLIT - smoke forecast

HMS Detected

Fire Pixels

HYSPLIT Dispersion Modeling

NAQFC/CMAQ Gases and PM Modeling

NWS/HYSPLIT Smoke Forecasting System

CONUS, AK: 0.2x0.2

HI: 0.05x0.05

CONUS: 0.15x0.15

AK: 0.10x0.10

HI: 0.05x0.05

BlueSky Fire Emissions Modeling
Updated BlueSky components in NWS HYSPLIT-smoke

• NWS/HYSPLIT smoke is being updated to use a newer version (v3.5.1) of the BlueSky.

• The updated BlueSky incorporates the Fuel Characteristic Classification System version 2 (FCCS2) over the continental US (CONUS) and Alaska, which includes a more detailed description of the fuel loadings with additional plant type categories.

• The updated BlueSky also uses an improved fuel consumption model and fire emission production system (FEPS).
TRIPOD FIRE CASE TOTAL FUELS
Top: 1-km maps
Bot: High-res maps

Courtesy of Susan O'Neal, USFS
### Advantage over operational BlueSky: Explicit description of Fuel Load type in Alaska region

<table>
<thead>
<tr>
<th>PROD Vegetation</th>
<th>EMC DEV Vegetation (FCCS2)</th>
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</thead>
<tbody>
<tr>
<td>Quartz Complex</td>
<td>Willow - Birch shrubland</td>
</tr>
<tr>
<td>Quartz Complex</td>
<td>Willow -- mountain alder shrubland</td>
</tr>
<tr>
<td>Quartz Complex</td>
<td>Black spruce / sphagnum moss forest</td>
</tr>
<tr>
<td>Quartz Complex</td>
<td>Black spruce / feathermoss forest</td>
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<tr>
<td>Quartz Complex</td>
<td>Cottongrass grassland</td>
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<tr>
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<td>Black spruce / sphagnum moss forest</td>
</tr>
<tr>
<td>Quartz Complex</td>
<td>Paper birch - quaking aspen - white spruce forest</td>
</tr>
<tr>
<td>Quartz Complex</td>
<td>Water</td>
</tr>
<tr>
<td>Quartz Complex</td>
<td>White spruce forest</td>
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<td>Quartz Complex</td>
<td>Cottongrass grassland</td>
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<tr>
<td>Quartz Complex</td>
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<tr>
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<td>Paper birch - quaking aspen - white spruce forest</td>
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<tr>
<td>Quartz Complex</td>
<td>White spruce - paper birch forest</td>
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#### PM25 smoke emissions comparison

- **Current operational BlueSky uses default fuel load type “Quartz Complex”** based on historical Quartz Complex fire in Canada.
- **The updated BlueSky provides an explicit description of fuel load in Alaska (Left panel).** Combined with more fuel load categories and updated emission processing, upper right panel shows the comparison of PM25 emission rates of the fires listed in the table.
- **The results of NWS/HYSPLIT smoke simulations on June 26 2015 show a larger column mean smoke PM25 concentration from using updated BlueSky than operational BlueSky (lower right panel).**

[Graph showing PM25 smoke emissions comparison]
The Canadian fire smoke impacts on the US air quality on June 9. Both NOAA/NESDIS HMS expert analysis (a) and GOES RGB image (b) indicate the smoke plume been transported from Canada to the upper Midwest and Northeast US (courtesy of Mark Ruminski). Both operational NWS/HYSPLIT smoke (PROD; c and e) and NWS/HYSPLIT smoke with updated BlueSky (EMC DEV; d and f) agree well with the observations and expert analysis both for the column (0-5000m; c and d) and surface layer (0-100m; e and f) mean PM25 concentration. GOES ASDA product (g) shows limited detection in similar area. NWS/HYSPLIT smoke with updated BlueSky leads to higher smoke concentration in the US than that of operational.
Similar to previous slide except for June 30 2015, but a mush stronger smoke intrusion case. Again, HYSPLIT-smoke captures the Canadian fire smoke intrusion in to the Midwest and Northeastern US. GOES ASDA product did not show the smoke concentration in the sarea.
NCEP Verification against GOES Atmospheric Smoke Detection Algorithm (ASDA) product

Better

Worse

Over forecast in higher threshold

But should be improved if GOES ASDA can capture some higher smoke concentration plume
Available web tools – but only for limited access

PROD/EMC-DEV HYSPLIT SMOKE Forecasts

HYSPLIT Verification
HYSPLIT 2013 Upgrades
HYSPLIT grib2 files
NESDIS fire smoke imagery
EMC AQ web site

HYSPLIT Forecast Smoke/PROD

HYSPLIT Forecast Smoke/DEV

Forecast Fires PROD

Forecast Fires DEV

GASP Observed Smoke

http://www.emc.ncep.noaa.gov/mmb/hchuang/web/html/hysplit_bluesky.html
Summary of HYSPLIT

• The next implementation of NWS HYSPLIT-smoke includes the updated BlueSky emissions module.

• Qualitatively, NWS HYSPLT-smoke can capture the heavy smoke plume traveling long distance.

• At present time, updated BlueSky has no explicit fuel load map for Canada (using default FCCS) and the fire emissions of Canadian can severely impact the US air quality, e.g., June 9 and 30 in the Northeastern US. The preliminary test shows the selection of default FCCS can influence the statistical score of model performance.

• It would be benefit to both HYSPLIT-smoke and CMAQ PM simulations to incorporate the smoke fire emissions of Canada such as the “FireWork” of Environmental Canada and/or “Canadian BlueSky” of Univ. of British Columbia.