Regional Air Quality Modeling Progress at NOAA/NWS/NCEP

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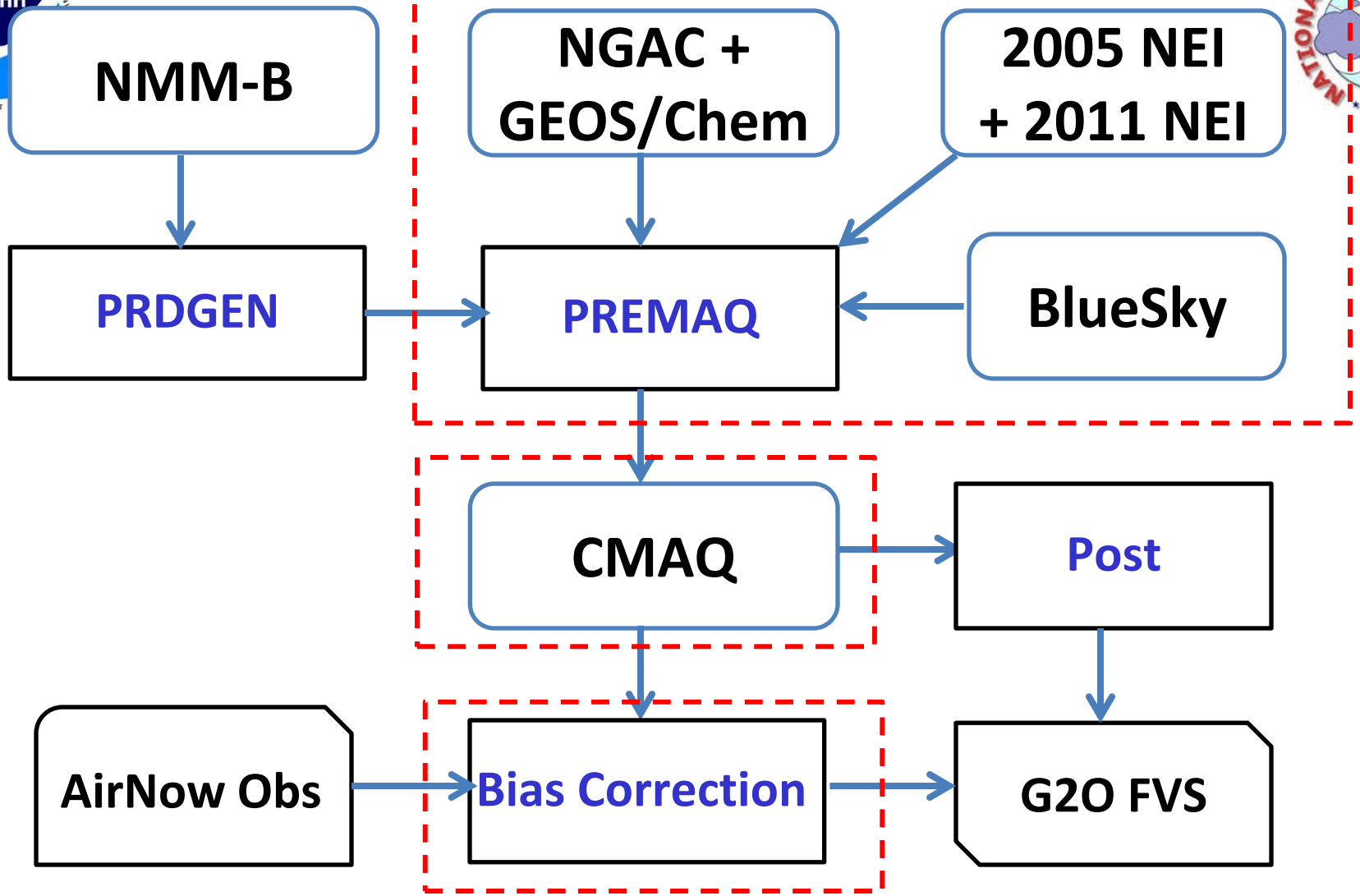
NAQFC: NMMB-CMAQ

- 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)



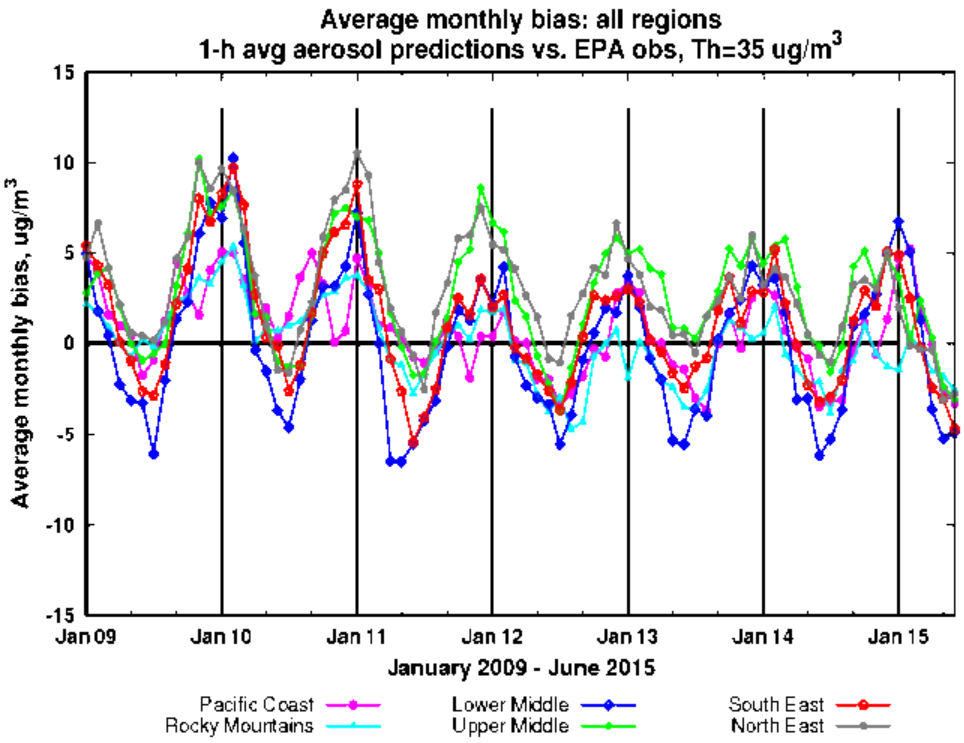
A flow-chart of the NMMB-CMAQ system

(new Changes as indicated by the red dashed boxes)

Current issues of $PM_{2.5}$ predictions

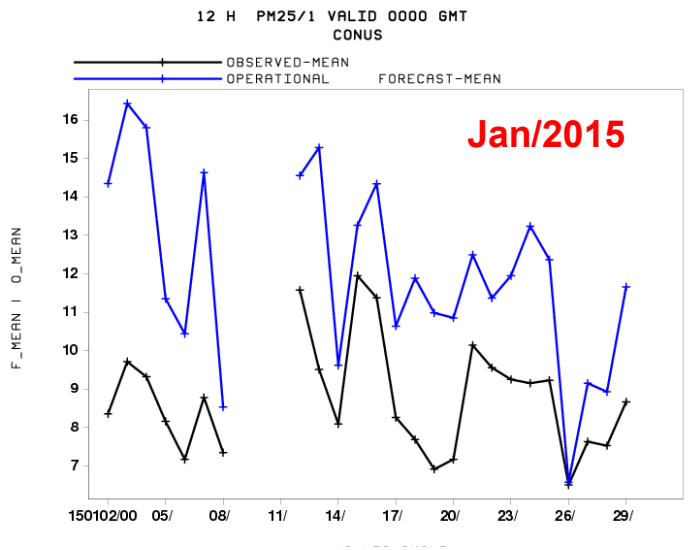
- Significant seasonal bias
  - over-prediction in winter
  - under-prediction in summer

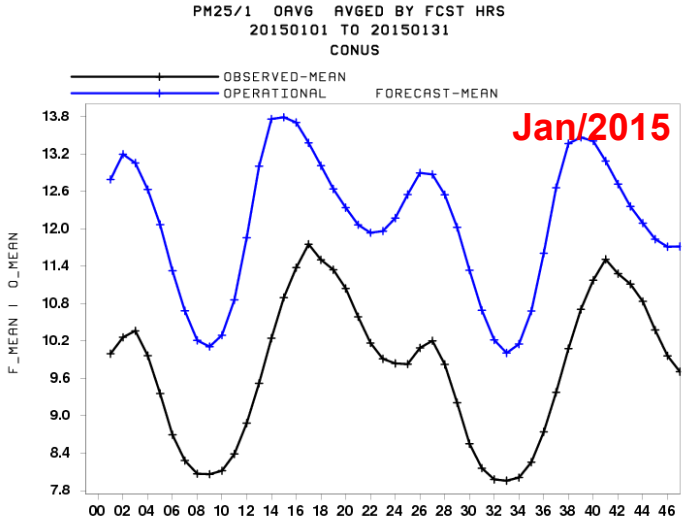
- Sources of the bias
  - emissions ?
  - Met inputs like PBLH ?
  - CMAQ itself?
  - LBCs?

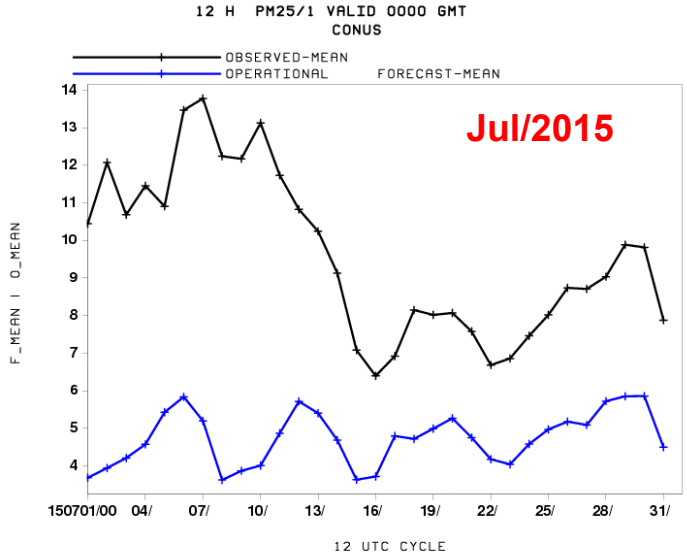


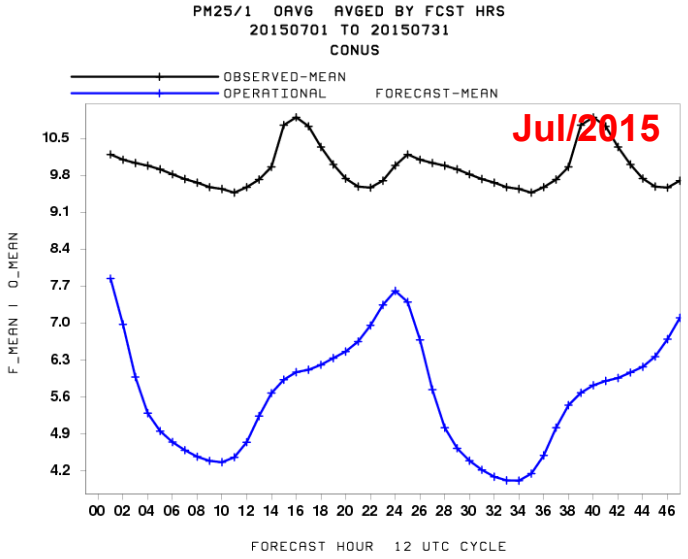
Over-prediction in winter is getting improvement and Under-prediction in summer is unchanged

Current issues of $PM_{2.5}$ predictions







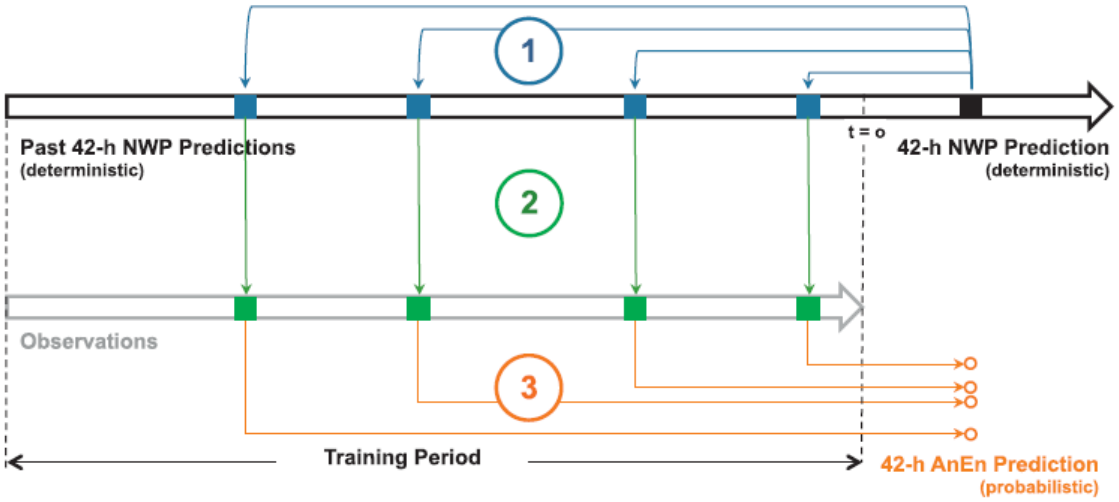


Approaches of $PM_{2.5}$ Bias Correction

- 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)

Djalalova et al. (Atmos. Environ. 2015)

Analog Ensemble in Probabilistic Weather Prediction



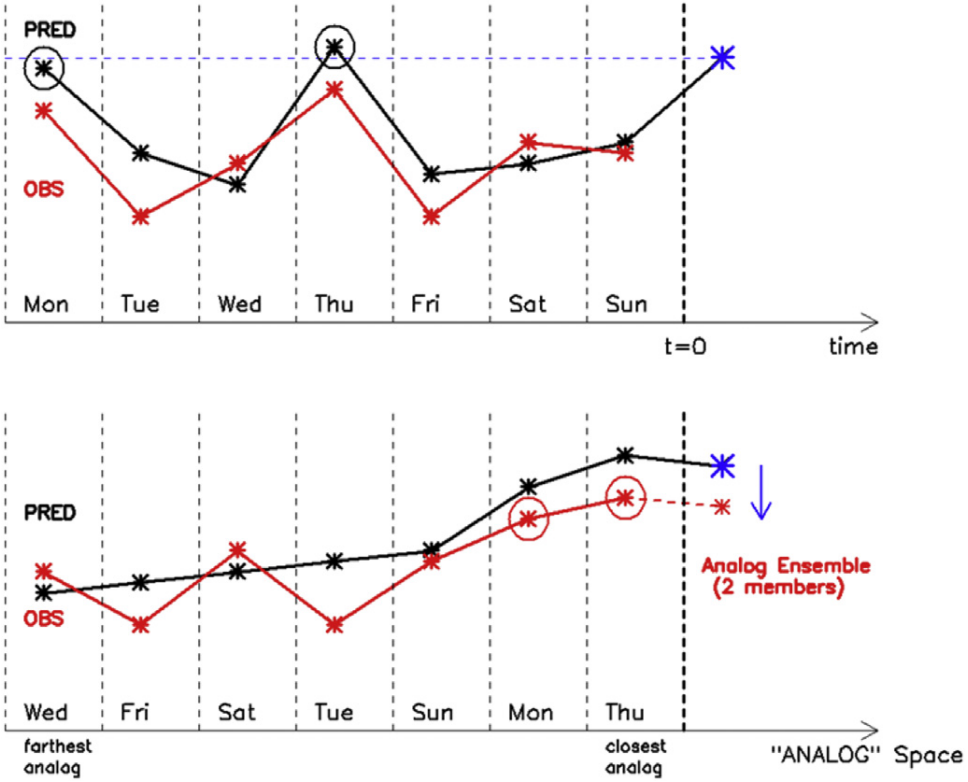
Analog metric is determined by (Monache et al. 2011)

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

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, σ_{f_i} standard deviation

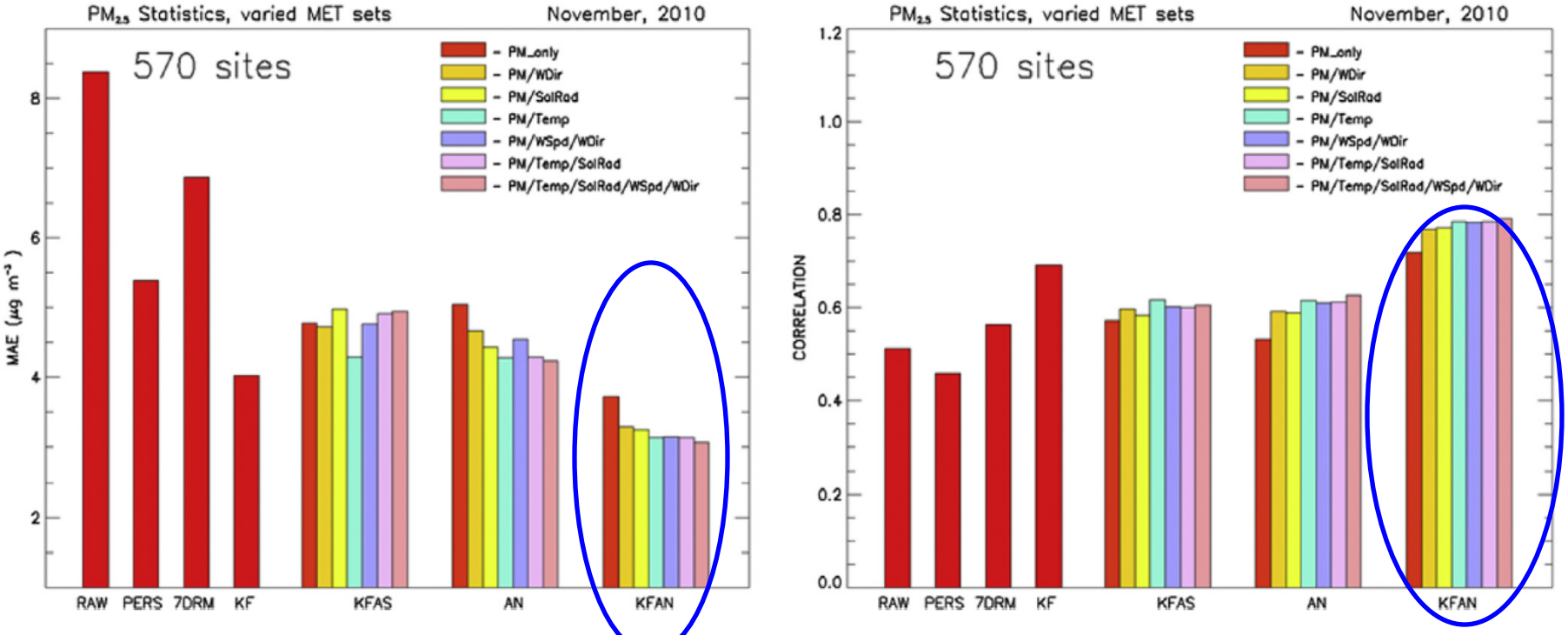
Analog Ensemble for $PM_{2.5}$ Bias Correction

- 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.)



MAE (left panel) and correlation coefficient (right panel) using hourly observed and forecast $PM_{2.5}$ values for the month of November, 2010 for the raw CMAQ model, persistence, and five different post-processing schemes. For the three analog methods, the color bars indicate the various combinations of search variables (i.e., analog predictors) used. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

KFAN shows the best performance

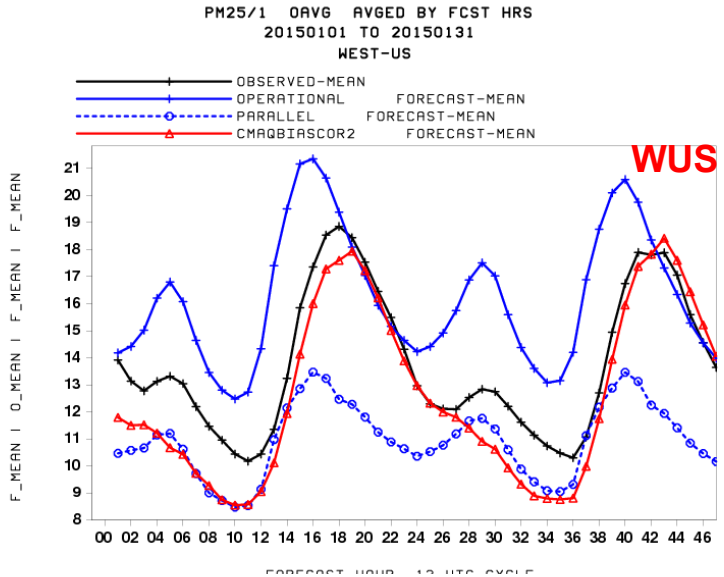
Analog search variables: $PM_{2.5}$, T, SR, WD, and WS

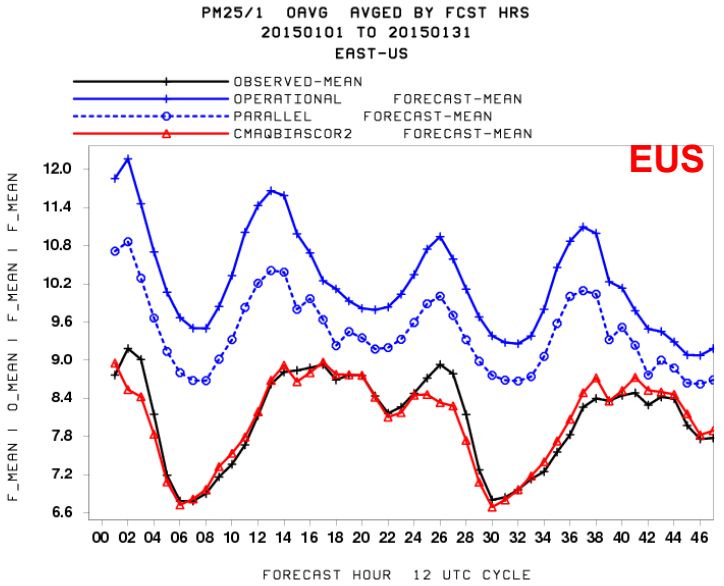
Djalalova et al. (Atmos. Environ. 2015)

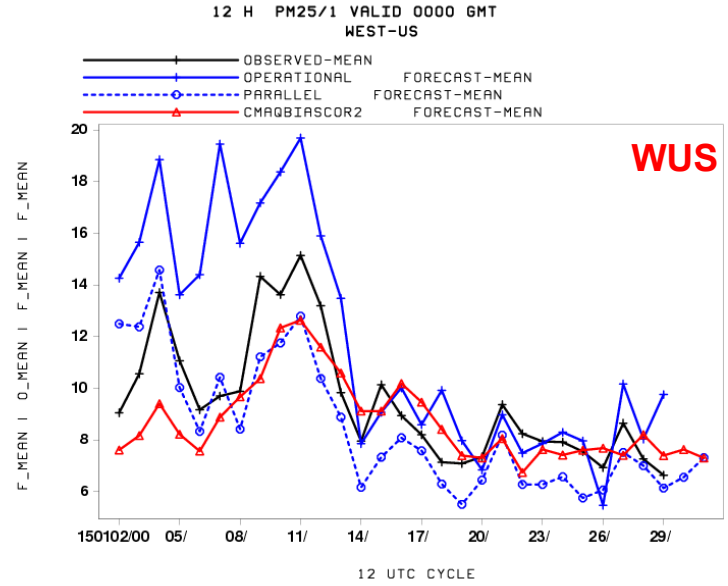
Configurations of NMMB-CMAQ runs

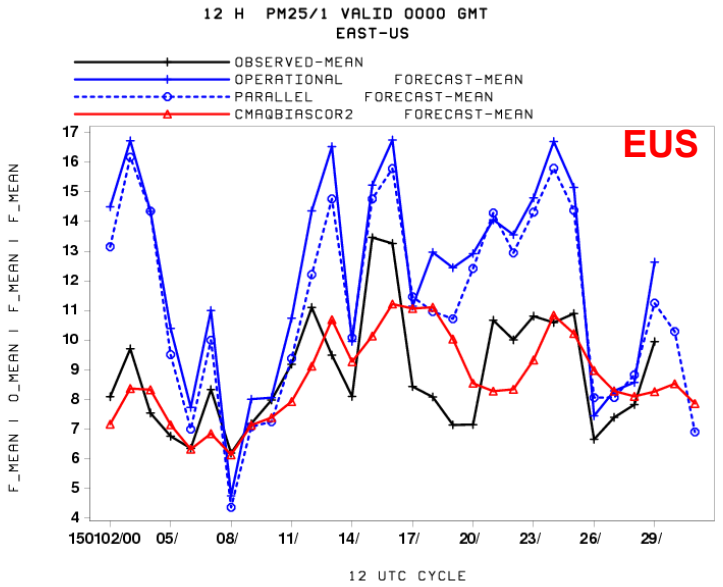
- Met inputs: NMMB 12-km (bgrd3d files)
- Emissions: 2005 NEI + part of 2011 NEI (without mobile sources) + Blue Sky fire/smoke emissions (no gas)
- CMAQ: CB05 gas-phase mechanism + Aero 4 module + 35 vertical levels
- Lateral Boundary Conditions: NGAC dust + 2006 GEOS/Chem simulations (for gas + others 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)

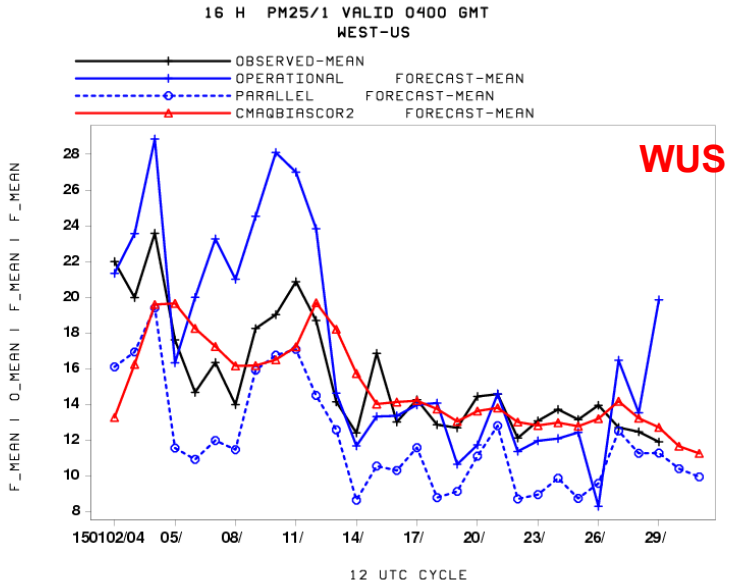


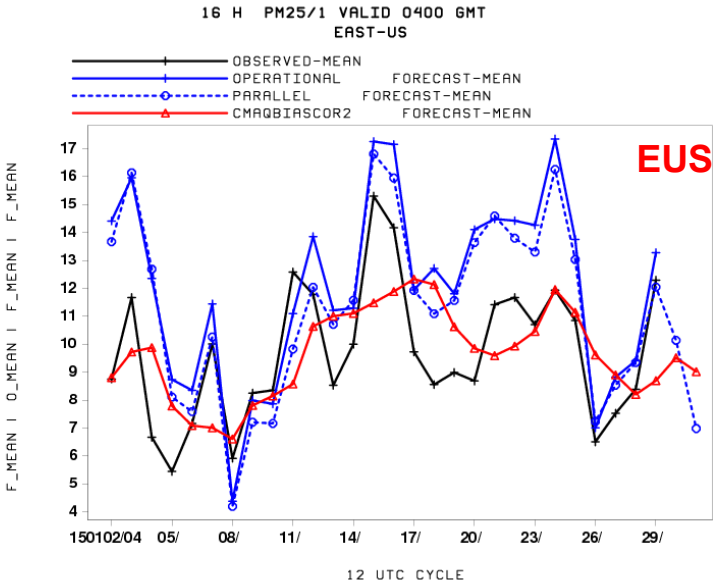


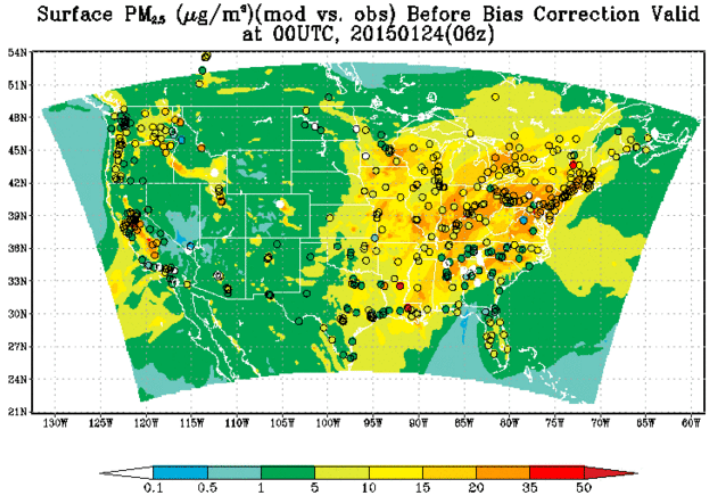


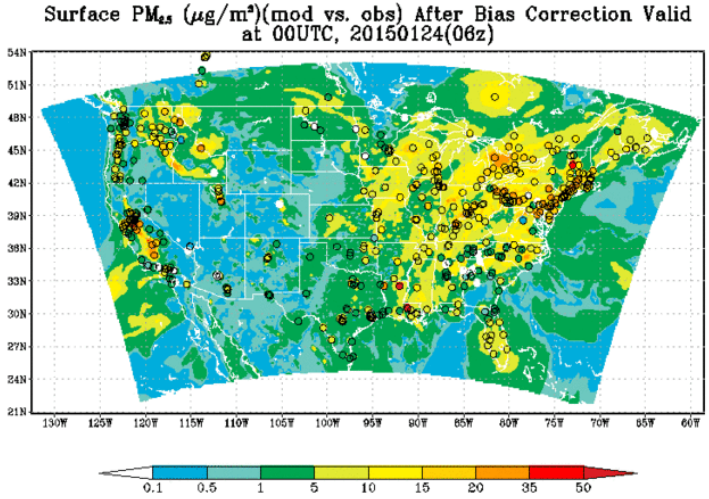


Testing for winter month (cont.)

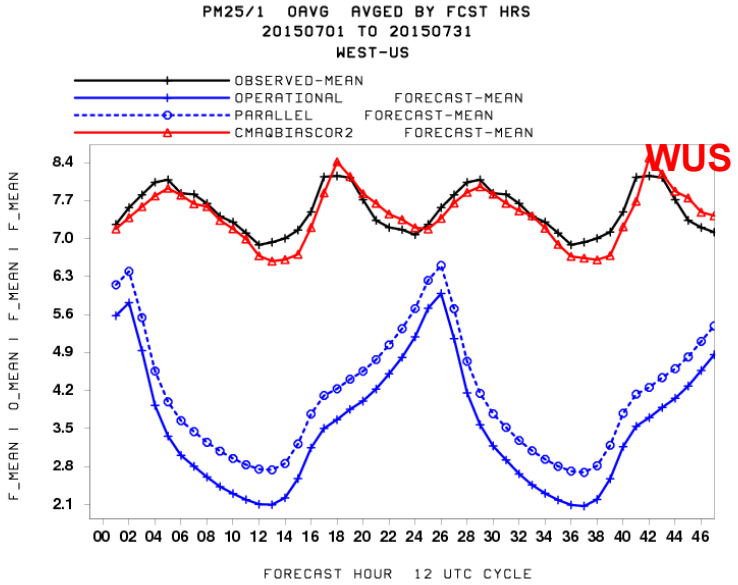


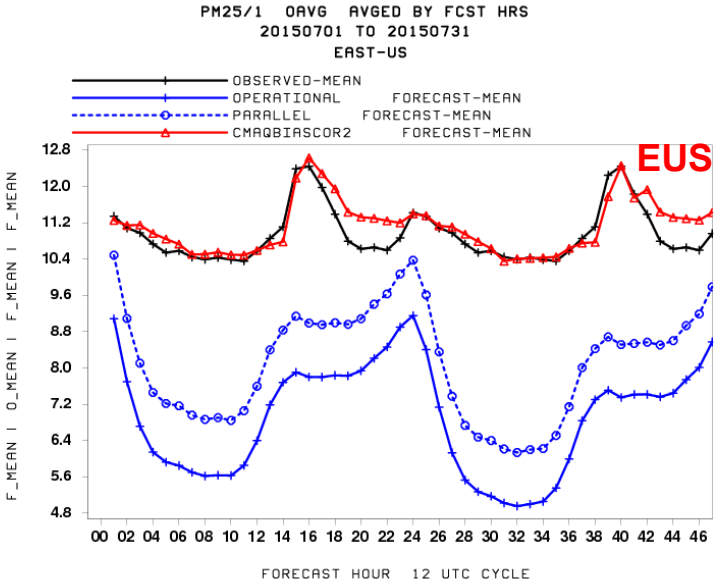


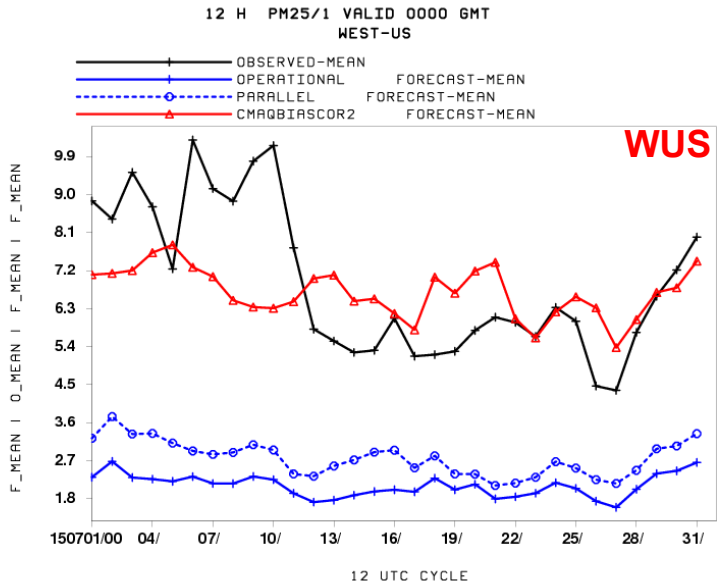


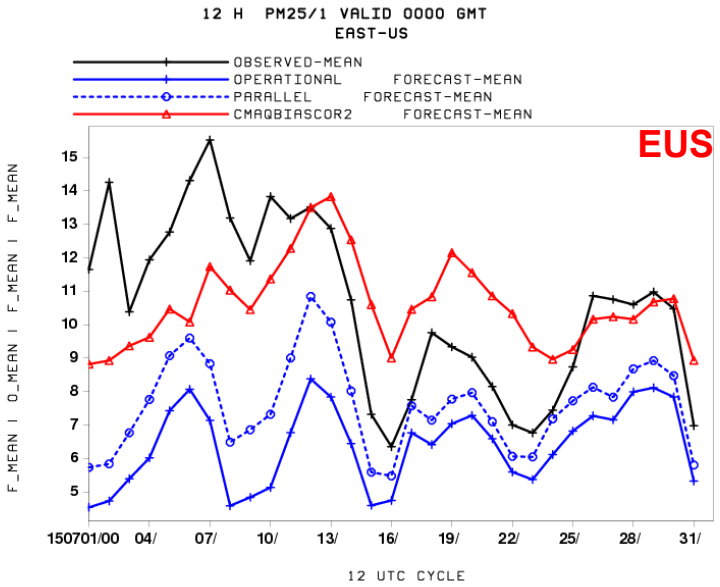


Testing for summer month(July 2015)

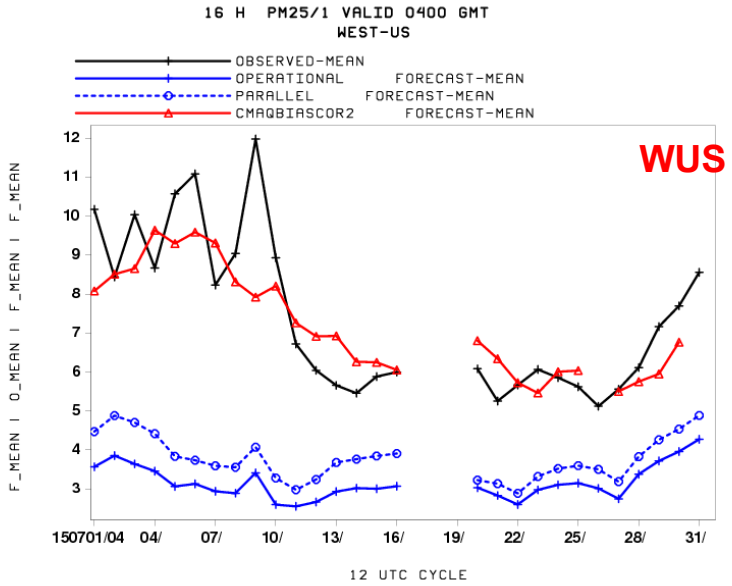


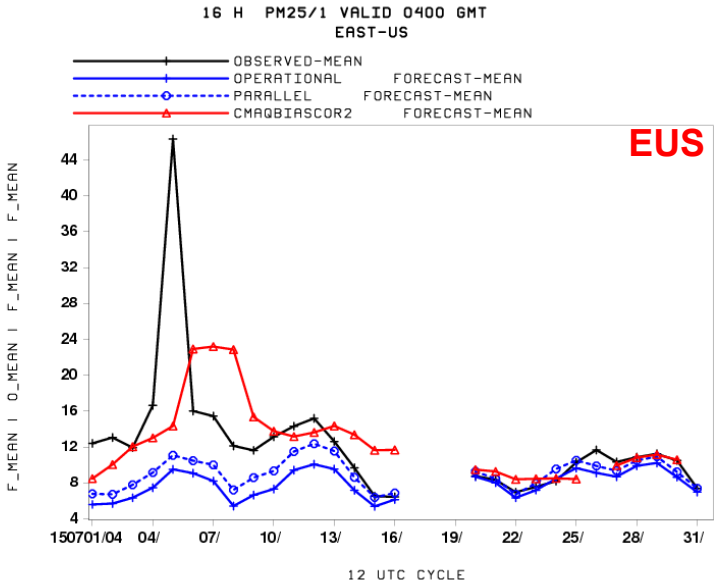


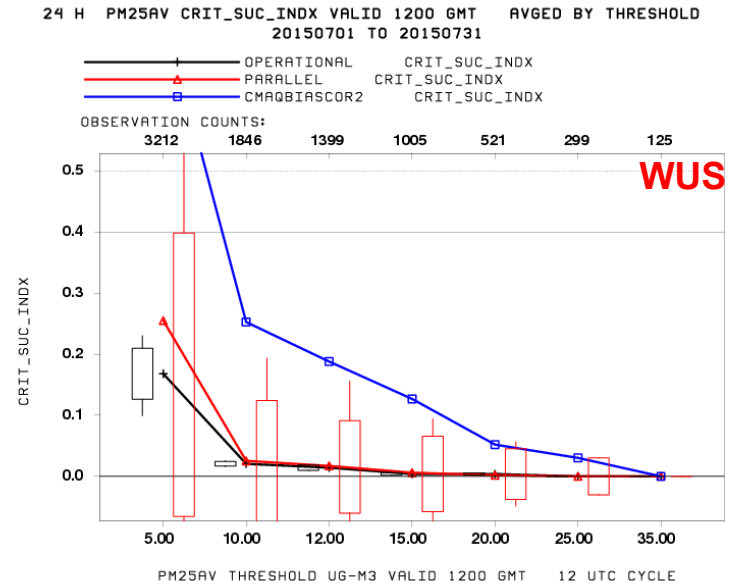


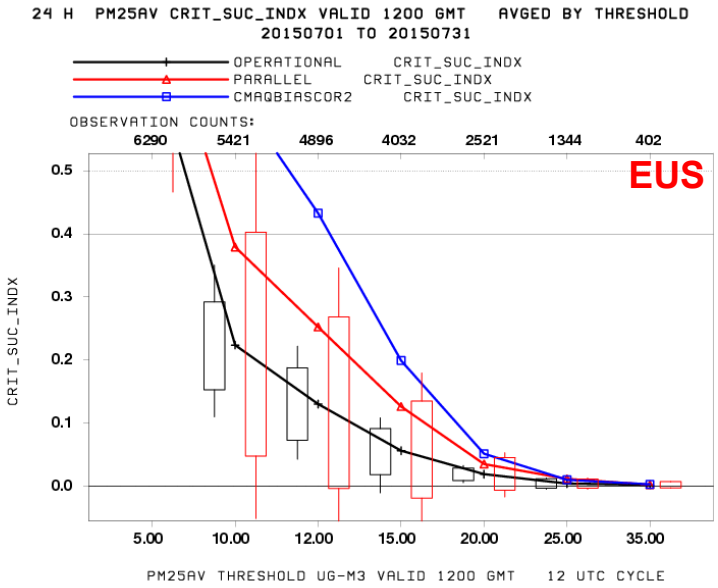


Testing for summer month(cont.)

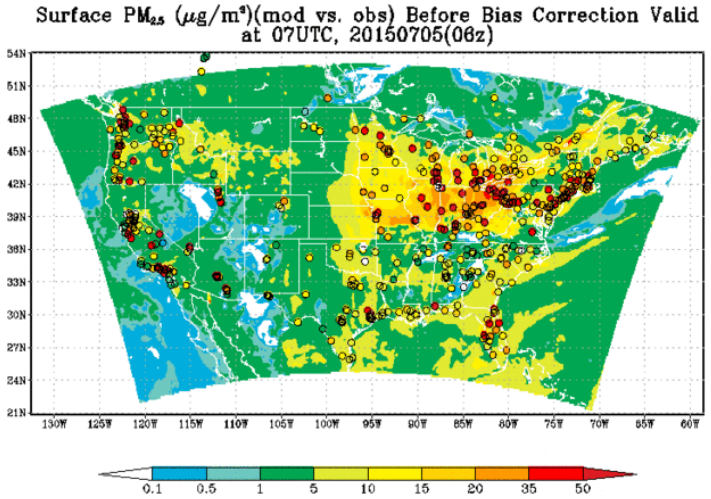


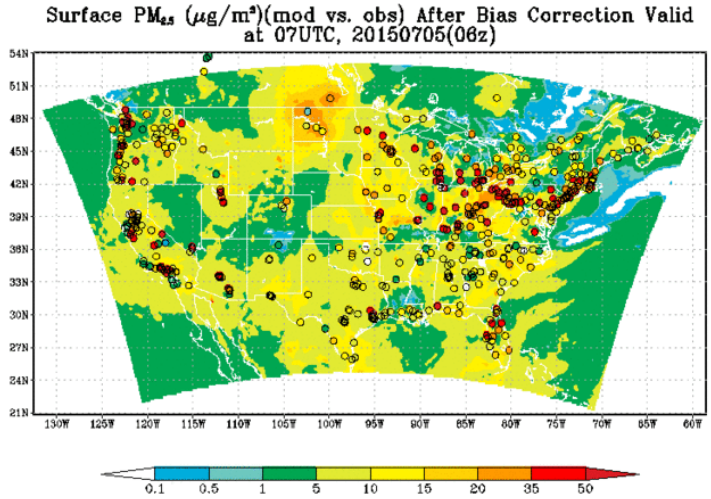


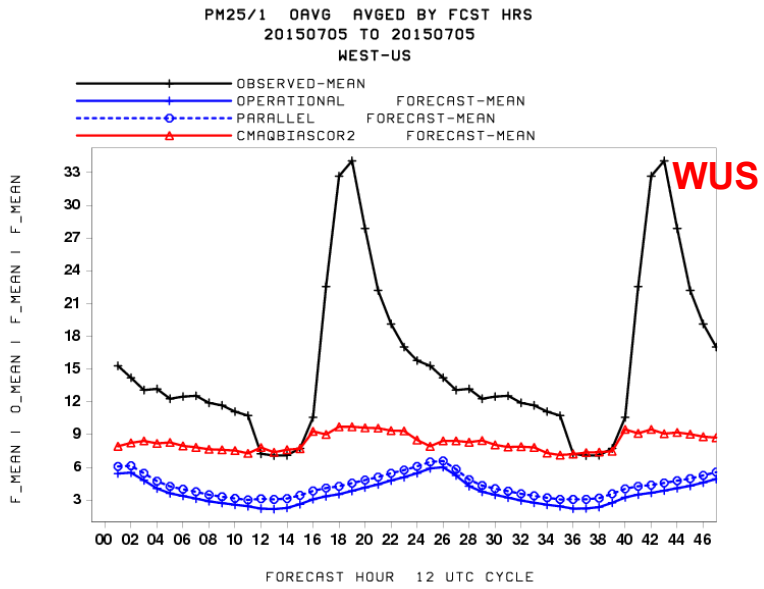


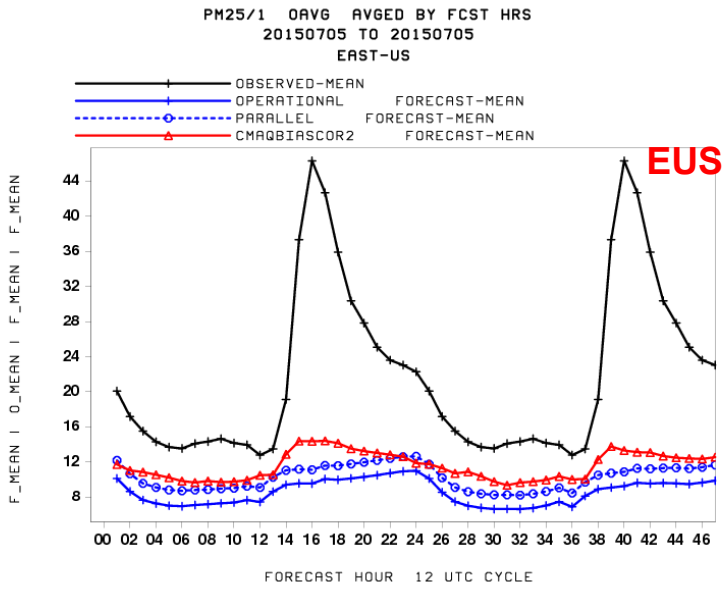


A case study on July 4th

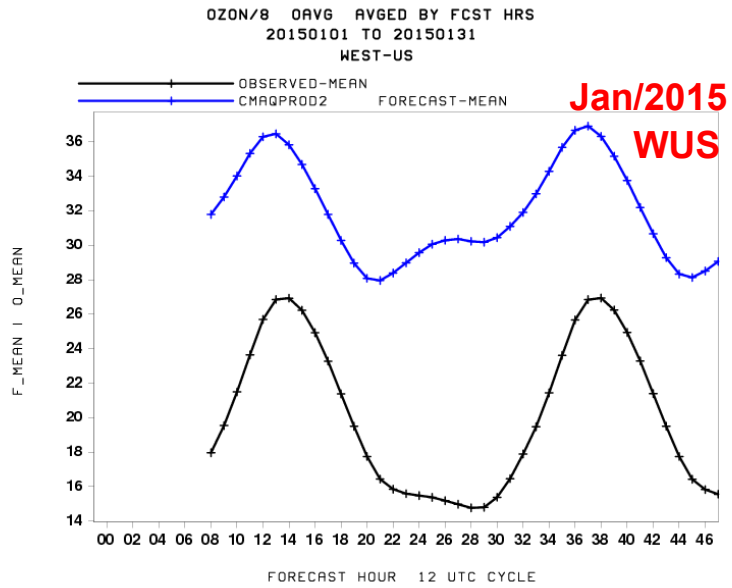


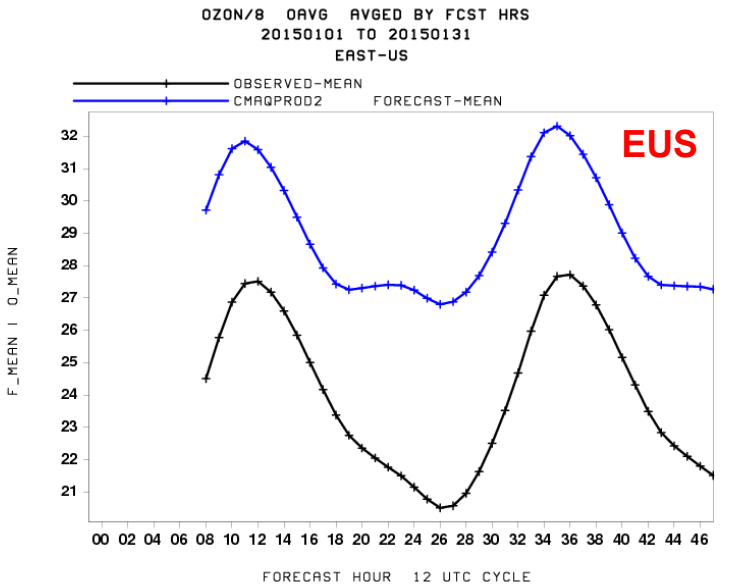


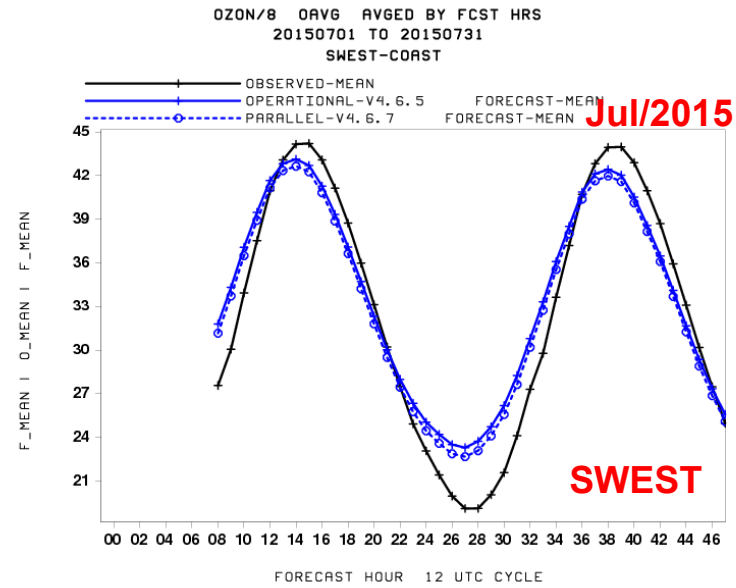


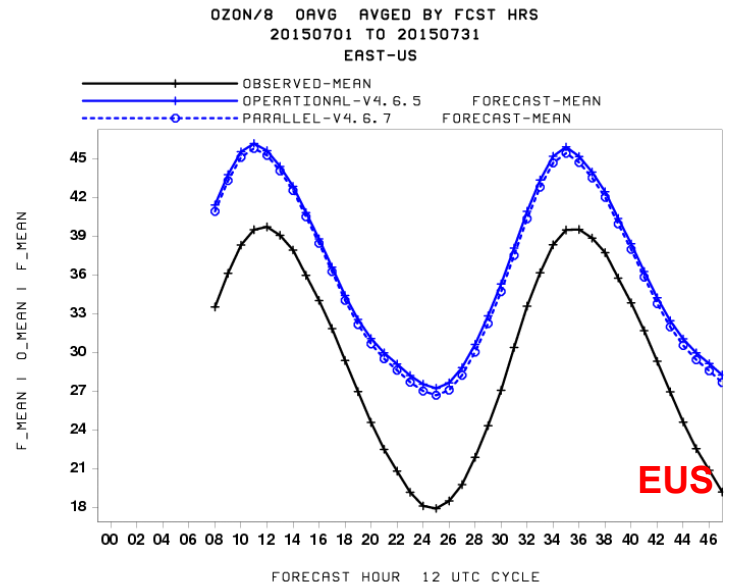


1-hr average Ozone









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

HYSPLIT Smoke Forecasting System

- 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.

BlueSky Fire Emissions Modeling

Updated BlueSky components in NWS HYSPLIT-smoke

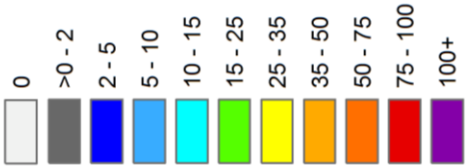
- NWS/HYSPLIT smoke is being updated to use a newer version (v3.5.1) of the BlueSky.
- The updated BlueSky incorporates the Fuel Characteristic Classification System version 2 (FCCS2) over the continental US (CONUS) and ***Alaska***, which includes a more detailed description of the fuel loadings with additional plant type categories.
- The updated BlueSky also uses an improved fuel consumption model and fire emission production system (FEPS).

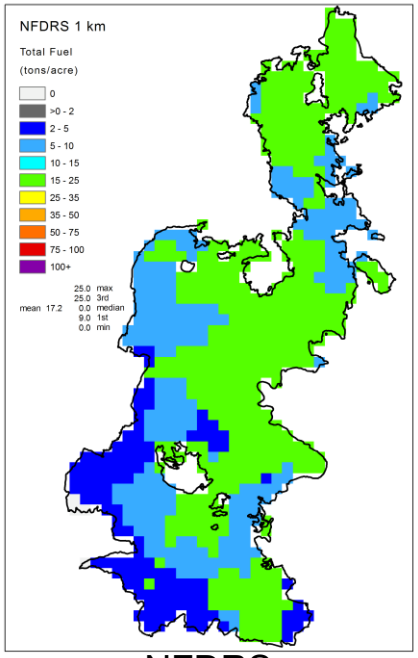
SEMIP Smoke and Emissions Model Intercomparison Project

TRIPOD FIRE CASE
TOTAL FUELS

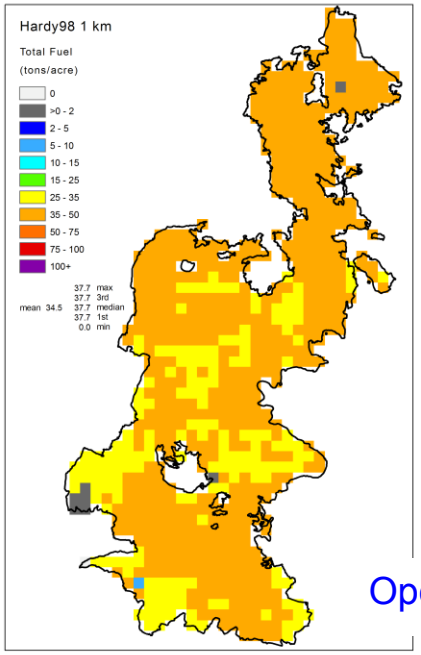
Top: 1-km maps

Bot: High-res maps



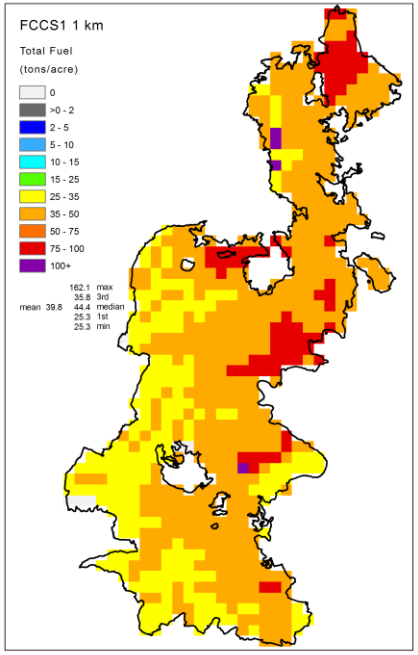


NFDRS

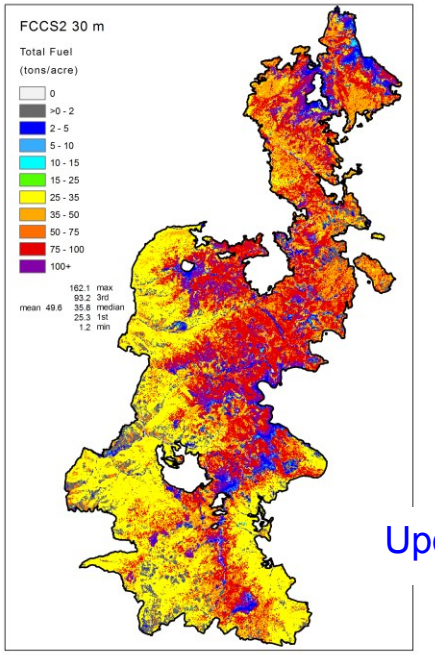


HARDY

Operational BlueSky



FCCS



FCCS-LF

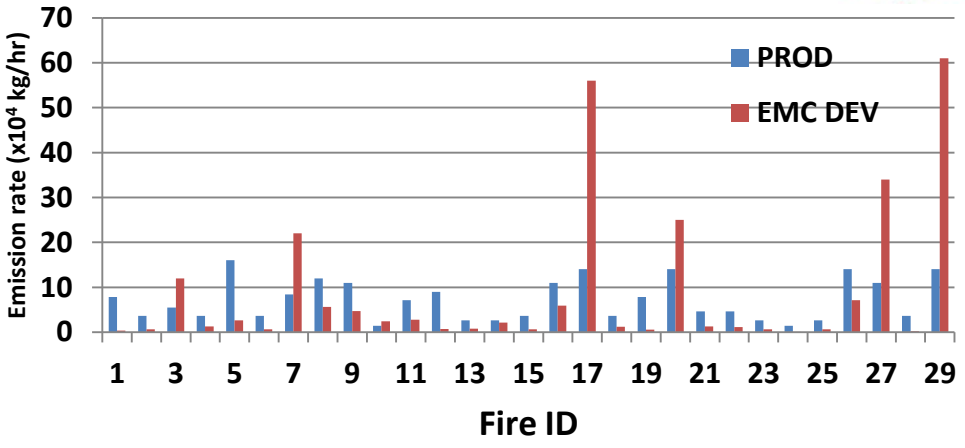
Updated BlueSky

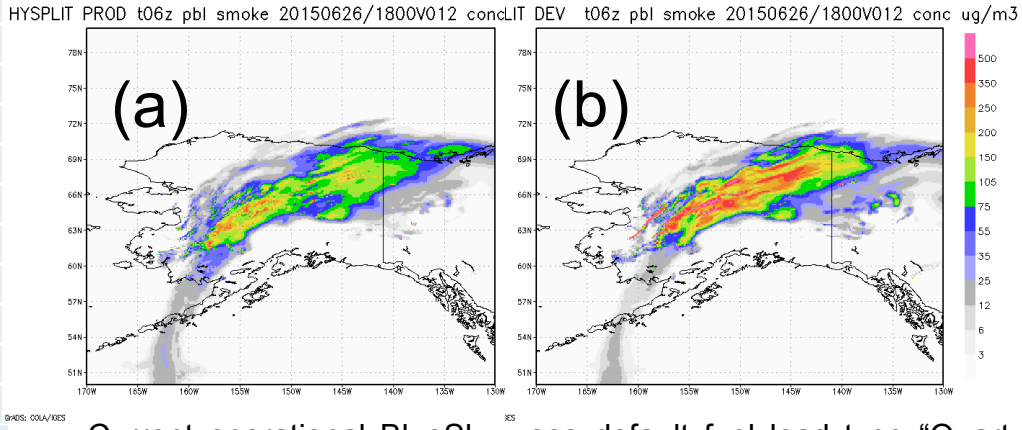
Courtesy of Susan O'Neal, USFS

Advantage over operational BlueSky: Explicit description of Fuel Load type in Alaska region

PROD Vegetation	EMC DEV Vegetation (FCCS2)
Quartz Complex	Willow - Birch shrubland
Quartz Complex	Willow -- mountain alder shrubland
Quartz Complex	Black spruce / sphagnum moss forest
Quartz Complex	Black spruce / feathermoss forest
Quartz Complex	Cottongrass grassland
Quartz Complex	Willow -- mountain alder shrubland
Quartz Complex	Black spruce / sphagnum moss forest
Quartz Complex	Paper birch - quaking aspen - white spruce forest
Quartz Complex	Water
Quartz Complex	Black spruce / sphagnum moss forest
Quartz Complex	White spruce forest
Quartz Complex	Cottongrass grassland
Quartz Complex	White spruce forest
Quartz Complex	Black spruce / cottonsedge woodland
Quartz Complex	Willow -- mountain alder shrubland
Quartz Complex	White spruce forest
Quartz Complex	Black spruce / sphagnum moss forest
Quartz Complex	White spruce forest
Quartz Complex	Cottongrass grassland
Quartz Complex	Black spruce / cottonsedge woodland
Quartz Complex	Paper birch - quaking aspen - white spruce forest
Quartz Complex	White spruce - paper birch forest
Quartz Complex	Paper birch - quaking aspen - white spruce forest
Quartz Complex	Willow - Birch shrubland
Quartz Complex	Paper birch - quaking aspen forest
Quartz Complex	Paper birch - quaking aspen forest
Quartz Complex	Black spruce / sphagnum moss forest
Quartz Complex	Cottongrass grassland
Quartz Complex	Black spruce / sphagnum moss forest

PM25 smoke emissions comparison

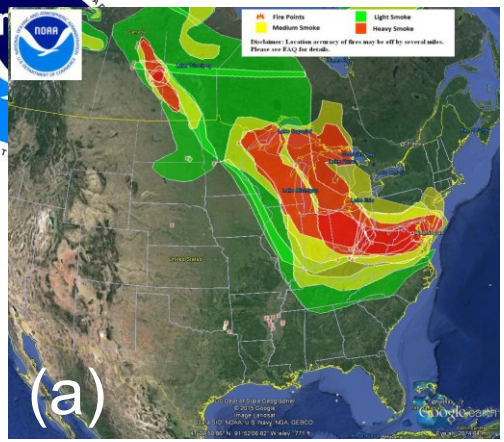


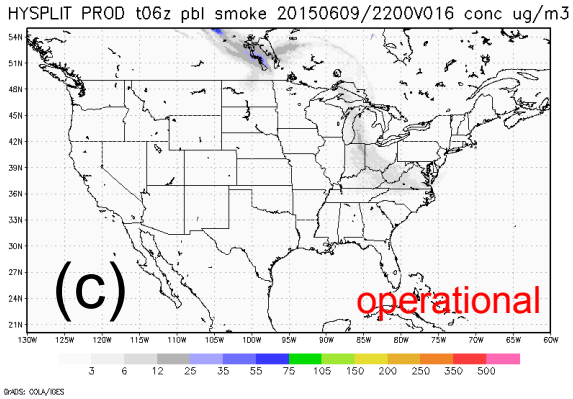


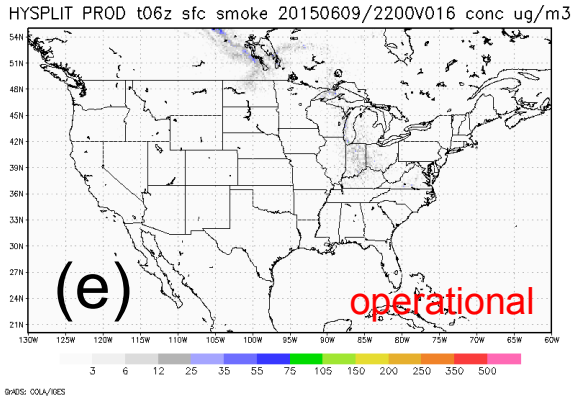
- Current operational BlueSky uses default fuel load type “Quartz Complex” based on historical Quartz Complex fire in Canada.
- The updated BlueSky provides an explicit description of fuel load in Alaska (Left panel). Combined with more fuel load categories and updated emission processing, upper right 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

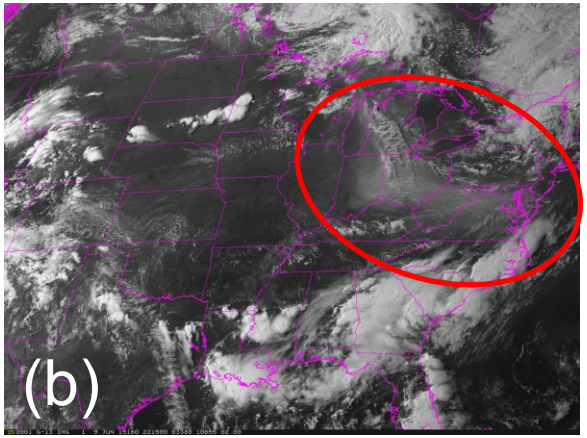
Column

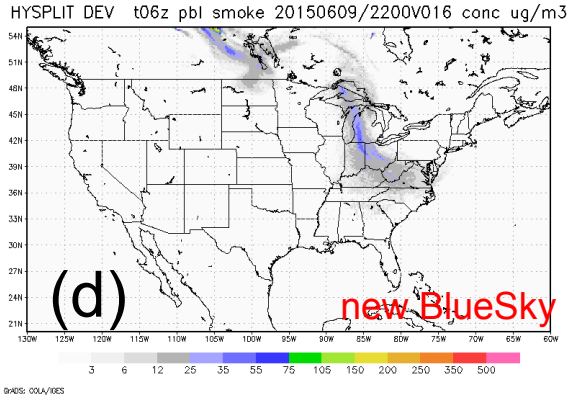
Surface layer

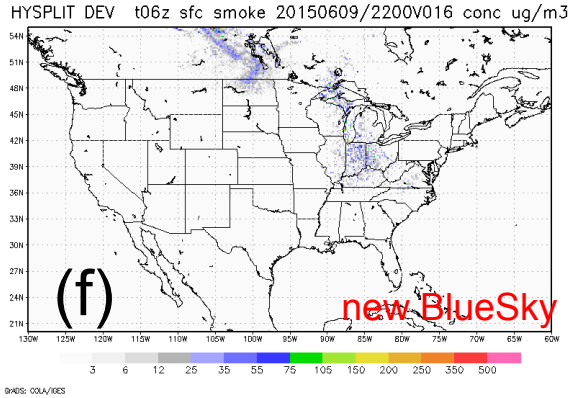




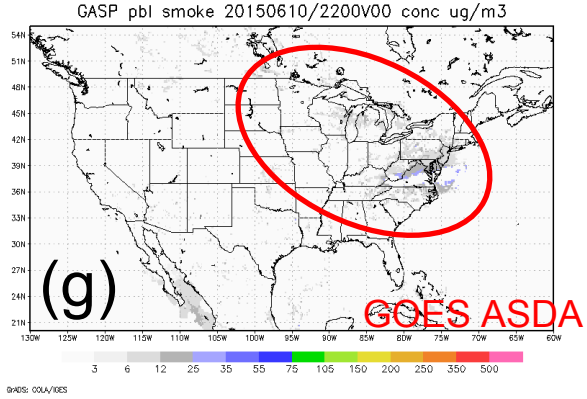








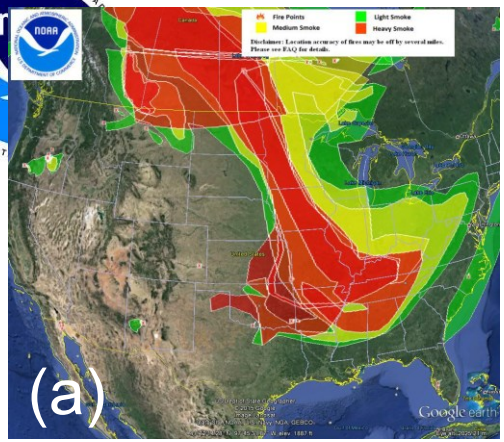
Column

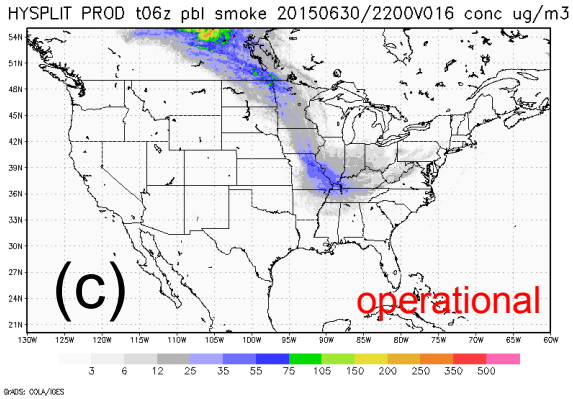


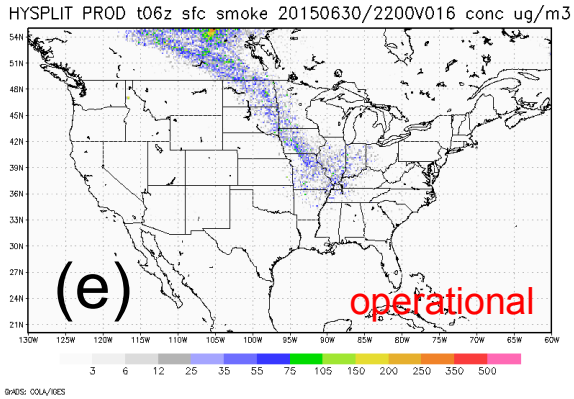
The Canadian fire smoke impacts on the US air quality on June 9. Both NOAA/NESDIS HMS expert analysis (a) and GOES RGB image (b) indicate the smoke plume been transported from Canada to the upper Midwest and Northeast US (courtesy of Mark Ruminski). Both operational *NWS/HYSPLIT smoke* (PROD; c and e) 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

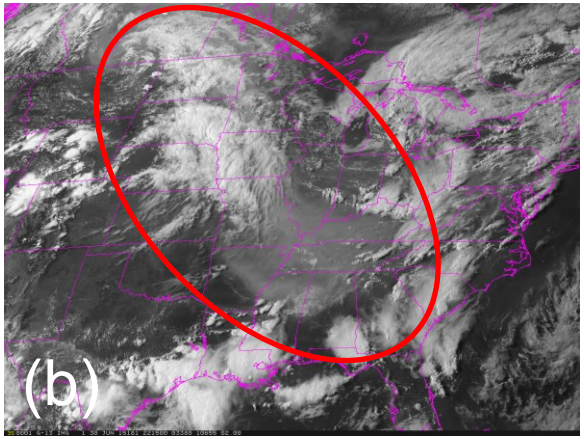
Column

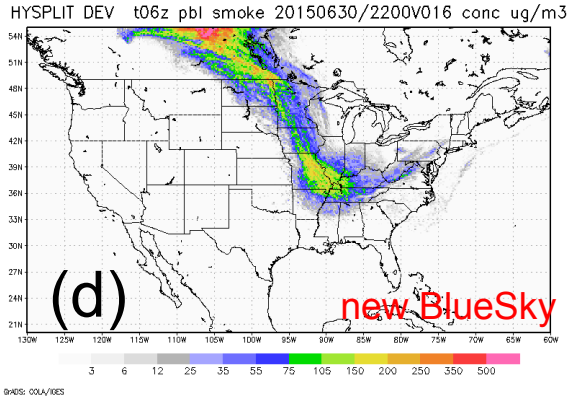
Surface layer

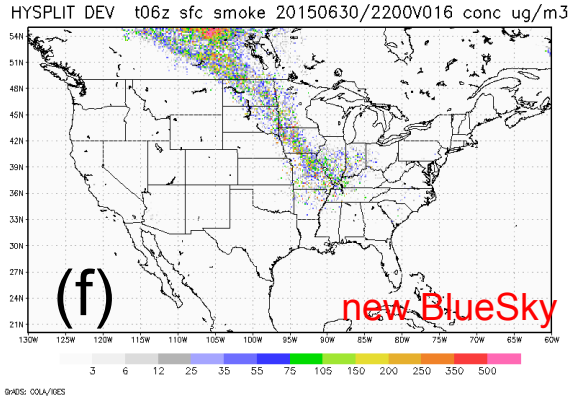




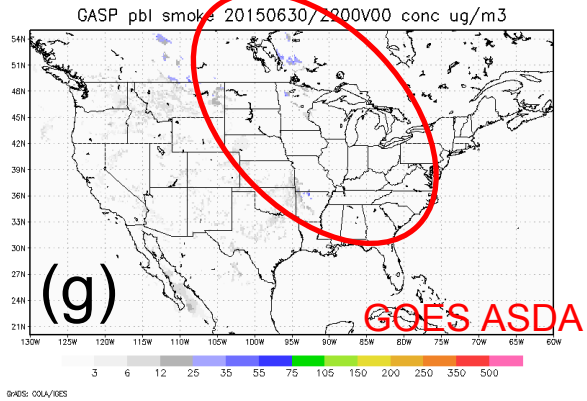






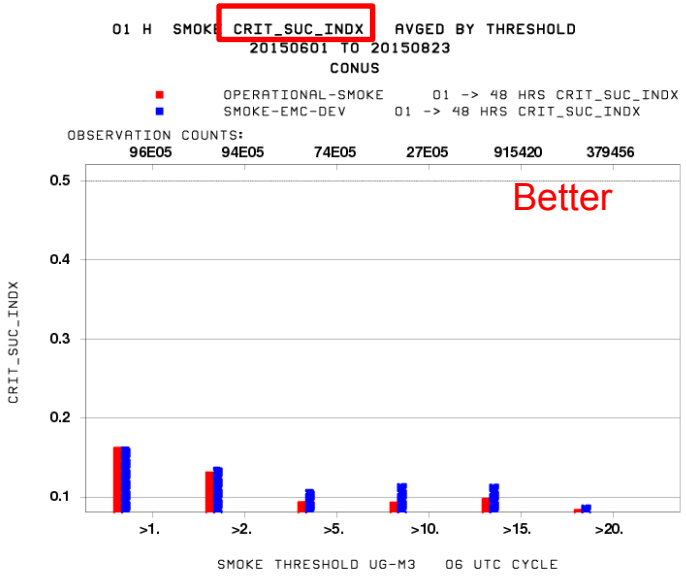


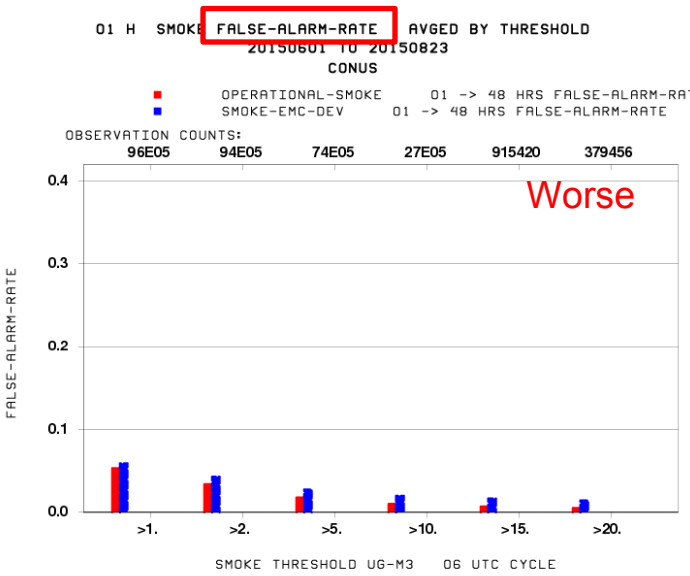
Column

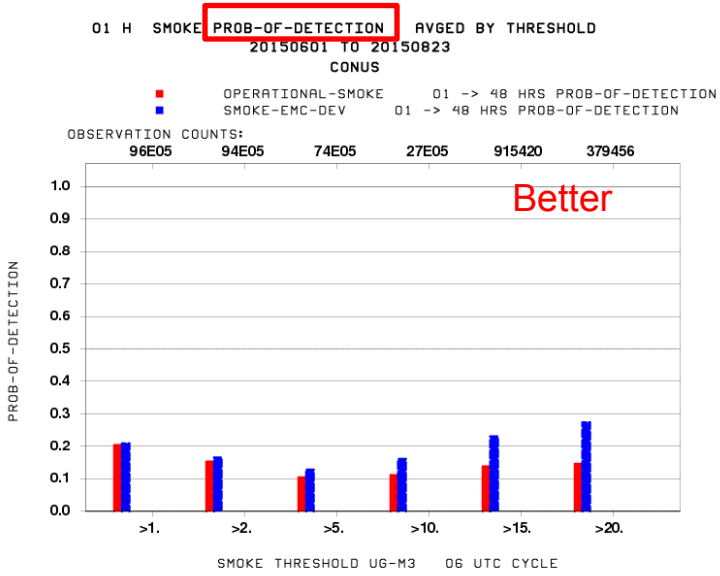


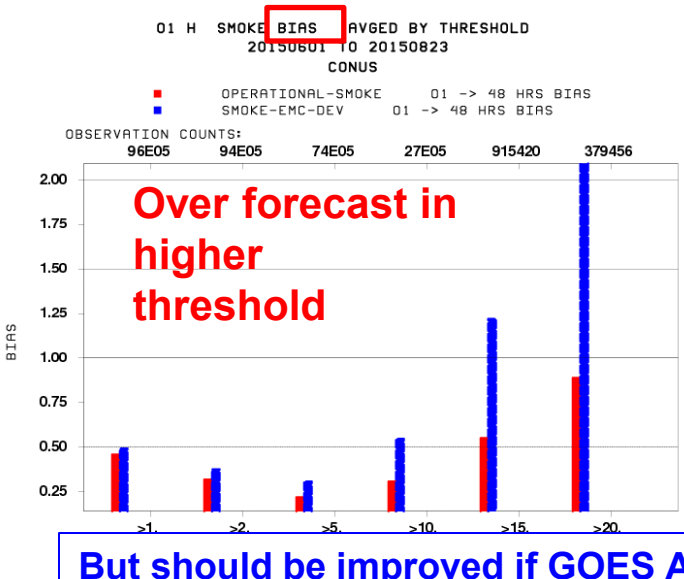
Similar to previous slide except for June 30 2015, but a mush stronger smoke intrusion case. Again, HYSPLIT-smoke captures the Canadian fire smoke intrusion in to the Midwest and Northeastern US. GOES ASDA product did not show the smoke concentration in the sarea

NCEP Verification against GOES Atmospheric Smoke Detection Algorithm (ASDA) product









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

03 06 09 12 15 18 21 24 27 30 33 36 39 42 45 48

Select speed: normal | Animation toggle | Stop | Continue | First | Prev | Next | Last

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

Change Type: HYSPLIT Smoke/dust plots

Region: Continental US

Year: 2015 Month: Aug Day: 14

Latest | Day-1 | Day+1

Select Cycle: 06Z

Select Field: Smoke Fine Particulate matter (ug/m3)

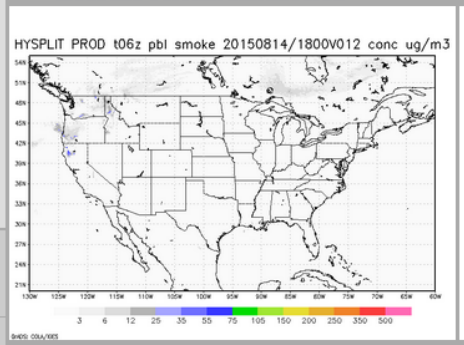
Select vertical level: Column Average

Display Image

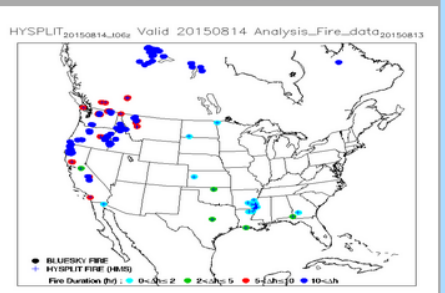
NAQFC
NCEP Home
NOAA Home

Send Comments

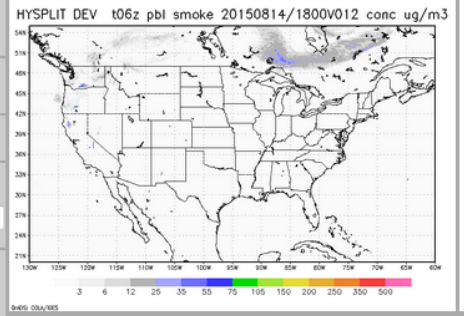
HYSPLIT Forecast Smoke/PROD



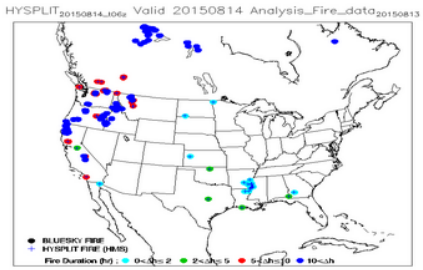
Forecast Fires PROD



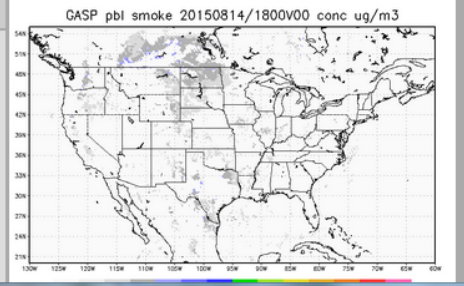
HYSPLIT Forecast Smoke/DEV



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.