Variational Assimilation of Surface Particulate Matter Observations in the experimental Rapid Refresh Forecast System coupled with Smoke and Dust Model

Hongli Wang[1,2*], Stephen Weygandt[2], Ravan Ahmadov[1,2], Ruifang Li[1,2], Johana Romero-alvarez[1,2], Haiqin Li[1,2], Jeffery Lee[3], Bo Huang[1,2], Youhua Tang[4], Cory Martin[5], Mohmmed Farooqui[6]

[1] CU/CIRES; [2] NOAA/GSL; [3] University of Oklahoma; [4]NOAA/ARL; [5]NOAA/NWS/NCEP/EMC; [6]Texas A&M University

Overview

Develop surface particulate matter (PM) assimilation capability for an experimental Rapid Refresh Forecast System Smoke and Dust (RRFS-SD) model:

- GSL has developed an experimental Rapid Refresh Forecast System Smoke and Dust (RRFS-SD) model that aims at operation in coming years.
- This presentation documents the recent development of surface Particulate Matter data assimilation scheme for providing accurate smoke and dust initial condition to the RRFS-SD model and evaluate the impact of the PurpleAir and AirNOW PM data on RRFS-SD smoke prediction.
- The prediction of the Sep 2020 fire event shows that the impact of the PurpleAir PM2.5 is comparable to the AirNOW observations during the peak of the fire event.

Experimental Configuration

RRFS-SD model

Category	Schemes
Deep CU	No
Microphysics	Thompson
PBL	RUC
Radiation	RRTMG Shortwave/Longwave Radiation Scheme
LSM	RUC
Deposition	Simplified Deposition
Fire Emission	Hourly Fire Radiative Energy (FRE) from RAVE dataset
Smoke Scheme	Revised version of Freitas
Dust Scheme	FENGSHA
Fire Feedback	No

Data Assimilation Experiment

- Control run
  - CONUS domain at 3km resolution
  - 6hourly cycling during 1-20 Sep 2020
  - Meteorological IBCs: RAP
  - SD tracers: cycled except for coldstart at 00Z Sep 1st 2020
  - 24h forecasts 4 times per day (00, 06, 12 and 18Z)
- PM_DA_B1
  - DA starts at 12Z Sep 1st 2020
  - AirNow PM2.5 is assimilated
  - Other setup is same to the control run
  - Background error statistics (B) was generated with forecasts in Feb 2023.
- PM_DA_B2
  - Same to PM_DA_B1 except for B was generated with forecast from the Control run.
- PA_DA_B2
  - Same to PM_DA_B2 except for assimilating **PurpleAir** PM2.5.

Verification

- Bias, RMSE, correlation
- 00Z 2nd Sep 2020

PM Data Assimilation for RRFS-SD

- **The PM DA capability is developed within GSI/3D-Var. The best analysis (x*) is the minimum of the cost function:**

$$J(\mathbf{x}) = \frac{1}{2}(\mathbf{x}-\mathbf{x}_b)^T\mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}_b) + \frac{1}{2}(\mathbf{y}_o - H(\mathbf{x}))^T\mathbf{R}^{-1}(\mathbf{y}_o - H(\mathbf{x}))$$

- **PM2.5 (particles with diameter 2.5 micrometers or less) observation operator (*H*)**

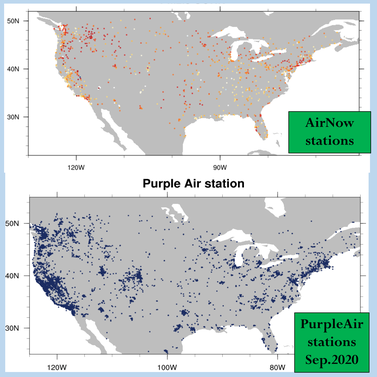
  PM2.5=smoke+dust

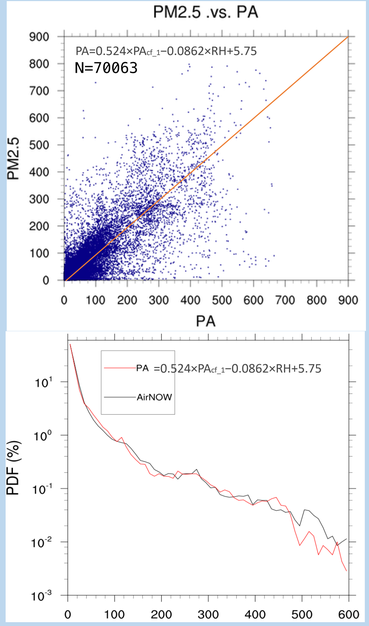
- **PM10 observation operator (*H*)**

  PM10=smoke+dust+coarsepm Option #1
  PM10=PM2.5(observed)+coarsepm Option #2

- **Conditional use of PM2.5**
  - Model predicted PM2.5 is larger than threshold 2.0 ug/kg and
  - abs(OMB) is larger than innovation threshold 15 ug/kg except for 30ug/kg in urban area, and
  - Surface temperature is greater than 5C .

AirNow and PurpleAir PM2.5 observations



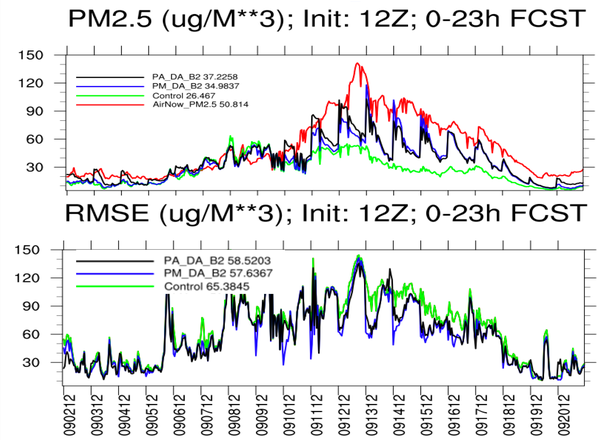


- PurpleAir (PA) is a community system of PM (10, 2.5, 1.0) low-cost ($200-300) sensors measuring particulate matter.
- PurpleAir PM2.5 needs to be bias corrected and quality controlled before they are assimilated.

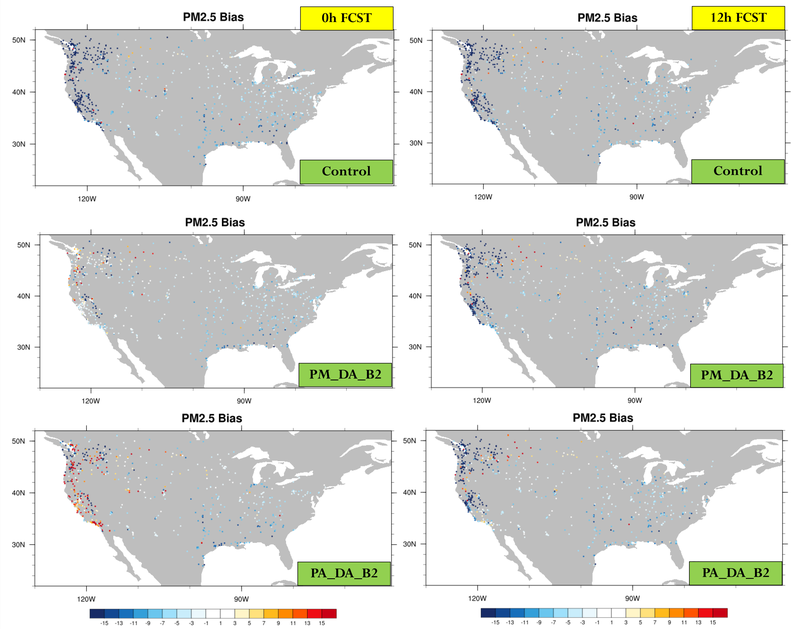
Summary

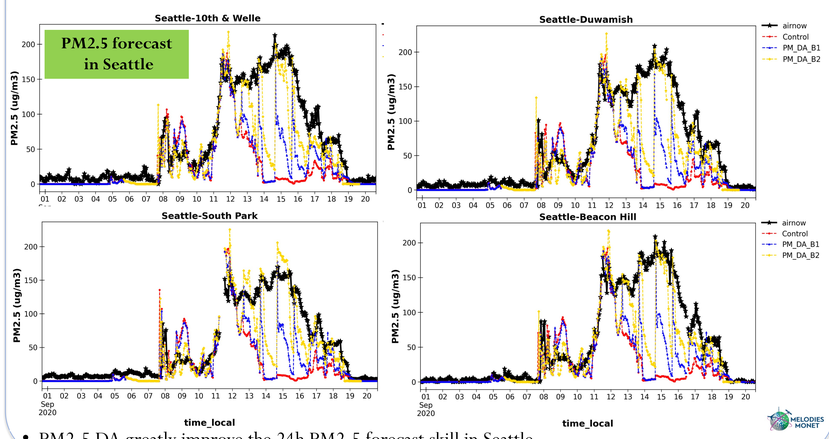
- Surface PM2.5 and PM10 assimilation capability for the RRFS-SD model is developed and evaluated with the fire events taking place in the US during September 2020.
- In general, PM2.5 DA improve the 24h smoke forecasts during the heavy fire events.
- The impact of the PurpleAir PM2.5 is comparable to the AirNOW observations during the peak of the fire events.
- The challenges are preprocessing PurpleAir PM observations, and providing accurate B estimate for 3D-Var.

PM DA Impact on Forecasts



- PM DA reduce the bias and RMSE in PM2.5 forecast in CONUS during the heavy fire events.





- PM2.5 DA greatly improve the 24h PM2.5 forecast skill in Seattle.

*Hongli.Wang@noaa.gov