Experiments with Assimilation of Surface PM2.5 Observations using GSI and EnKF with WRF-Chem during Summer 2010.

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GSI vs. EnKF

- GSI – 3DVAR: use static background error statistics usually derived from climatology such as e.g. NMC method (48-hr fcst – 24-hr fcst); solve variational problem to obtain optimal solution given model and observation errors.

- EnKF: obtain state dependent model errors from an ensemble of simulations; solve for an optimal solution using Kalman filter equations; more computationally expensive because of the need for multiple ensemble forecasts but potentially better estimates of model errors.

Observations and Model

Real-time PM2.5 measurements network AIRNow

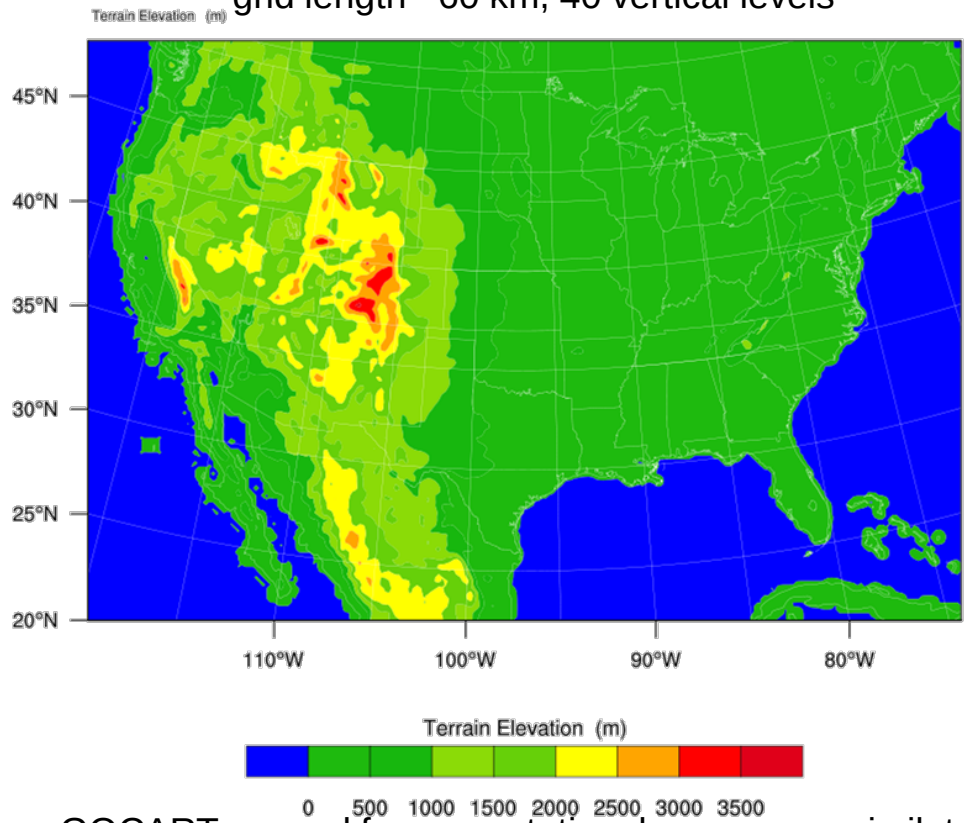
Total aerosol mass;

1-hr average available round the clock;

urban, suburban, rural sites.

ARW WRF-Chem updated version 3.2.1

grid length ~60 km, 40 vertical levels



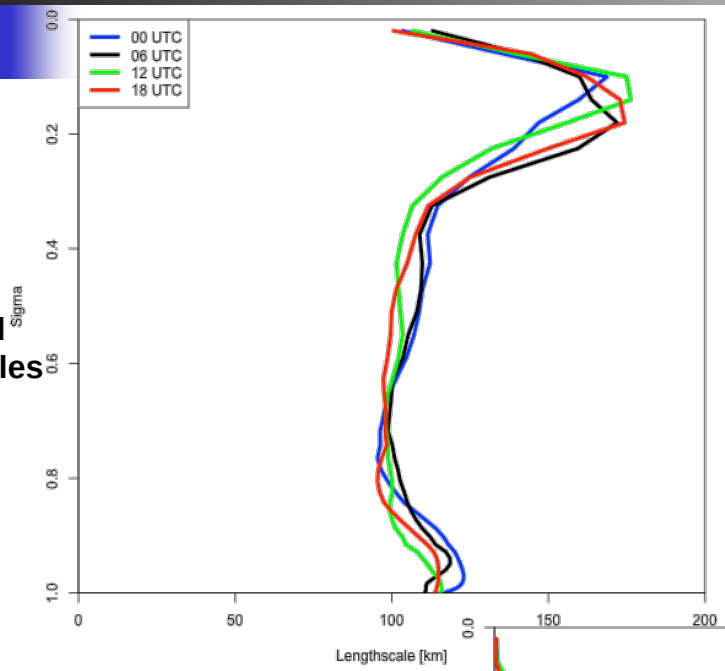
GOCART aerosol for computational reasons, assimilate standard meteorological observations (prepbufr) and AIRNow PM2.5 in 6-hr cycle with 1-hr window, NMM lateral boundary conditions;

GSI: Background Error Statistics derived from continuous forecasts in summer 2006 using NMC method;

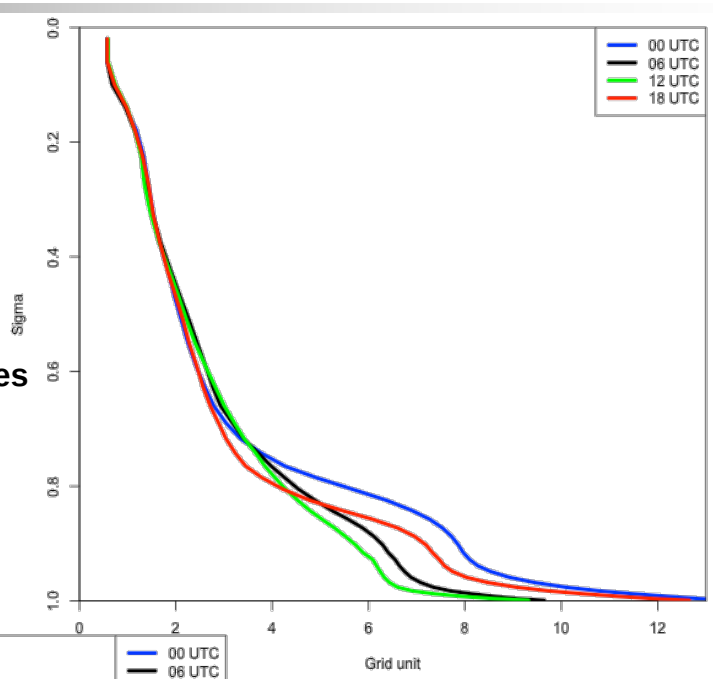
EnKF: 50 ensembles initialized from NMM using background error statistics and perturbing emissions.

Background Error Statistics (GSI)

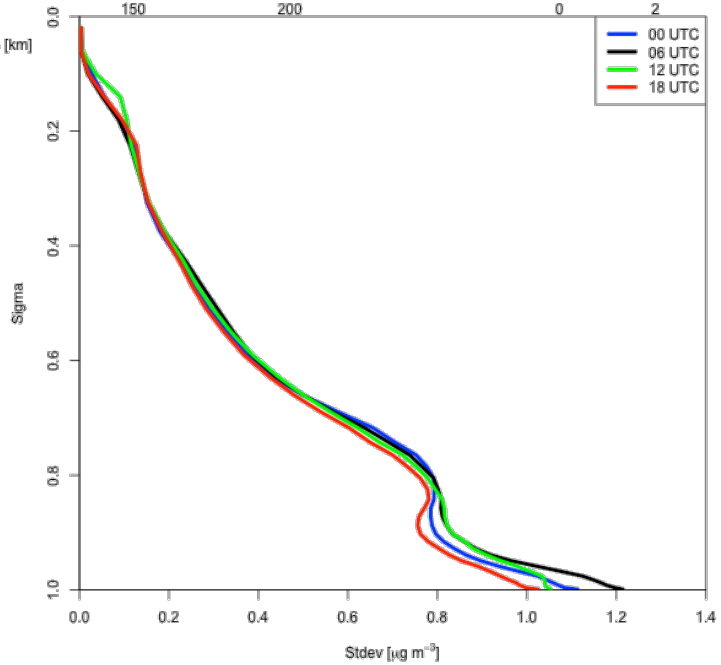
Horizontal lengthscales



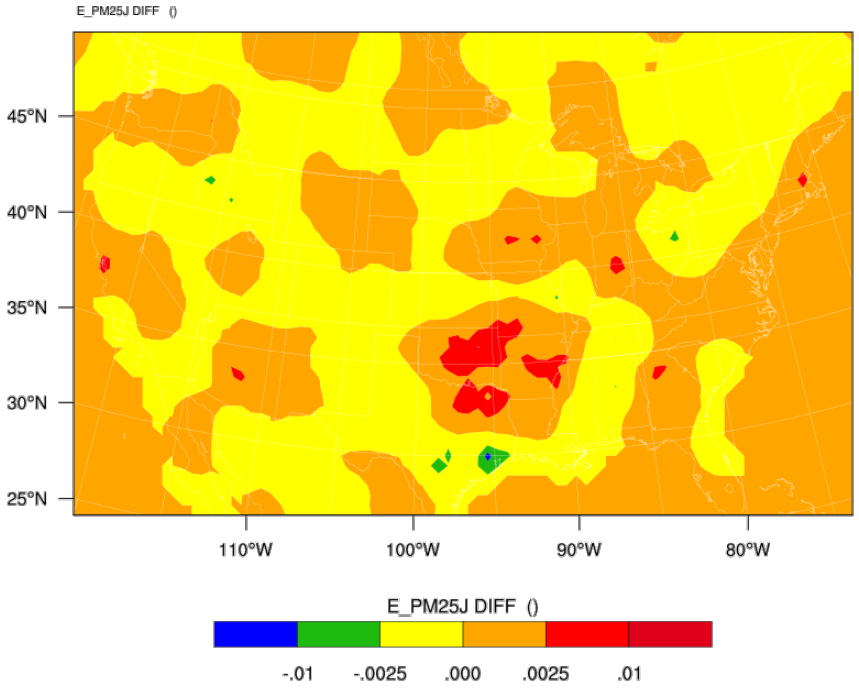
Vertical lengthscales

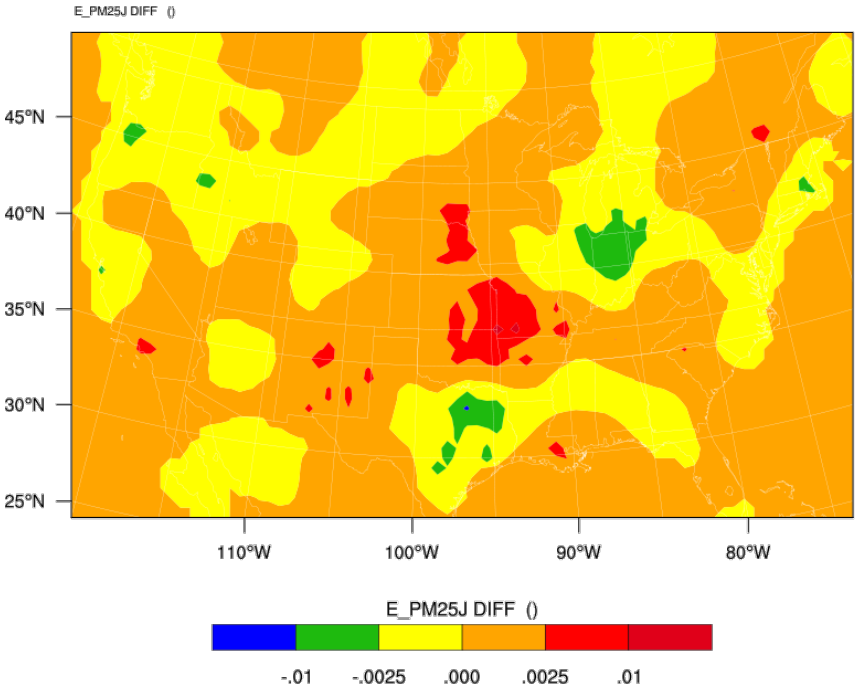


Standard deviations

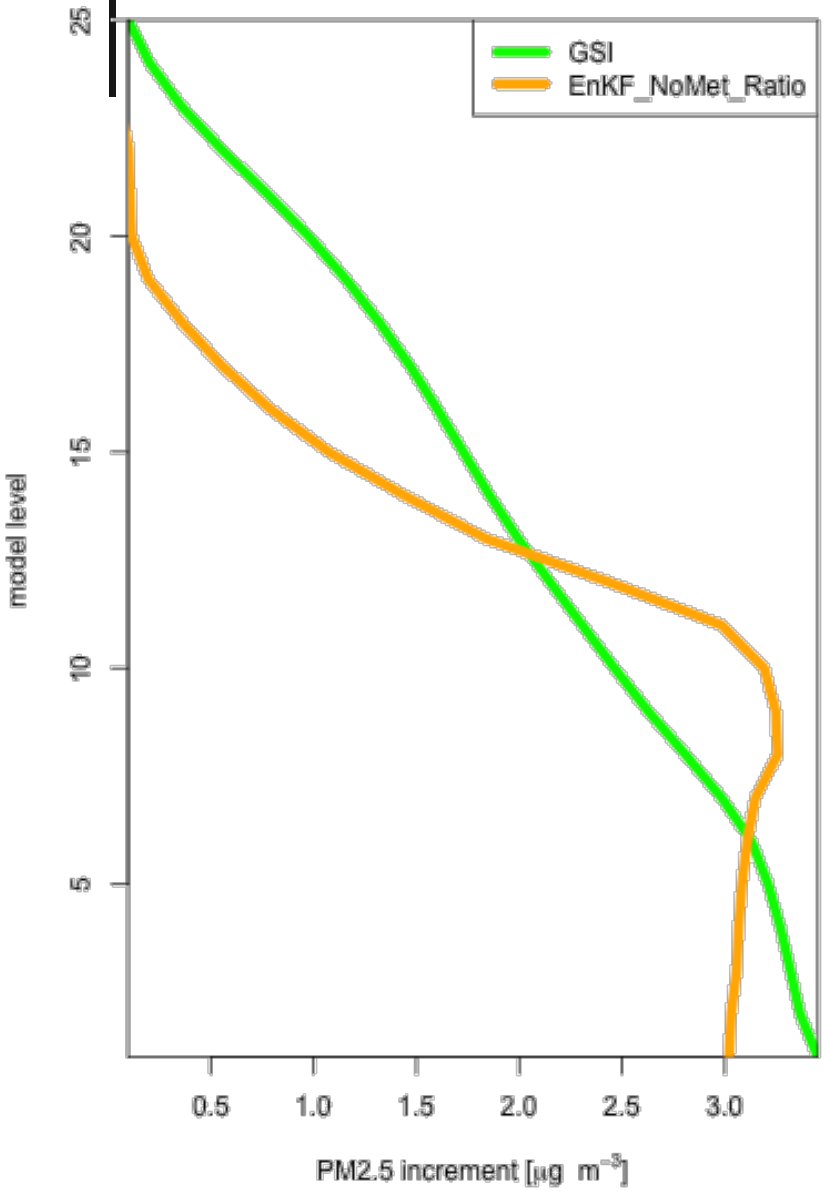


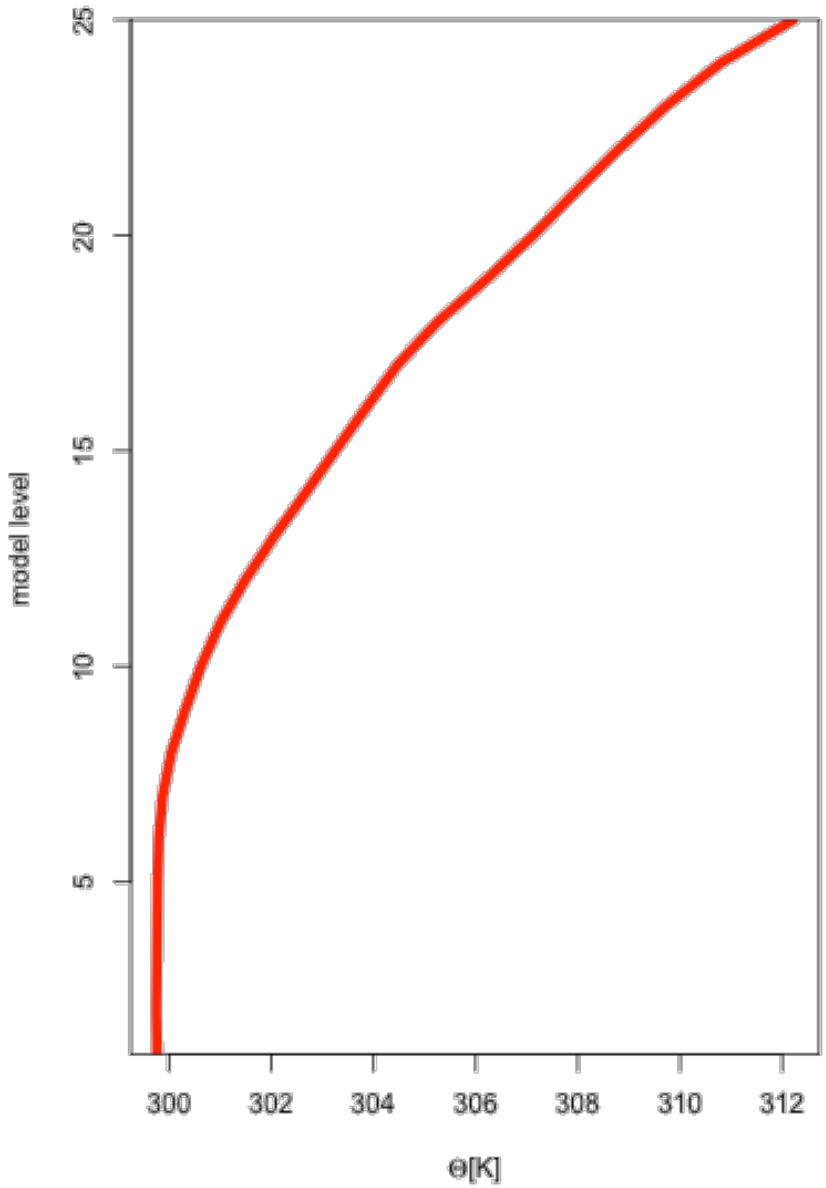
Surface Emissions Perturbations (EnKF) – PM2.5J example





PM2.5 increment at 12 UTC – an example





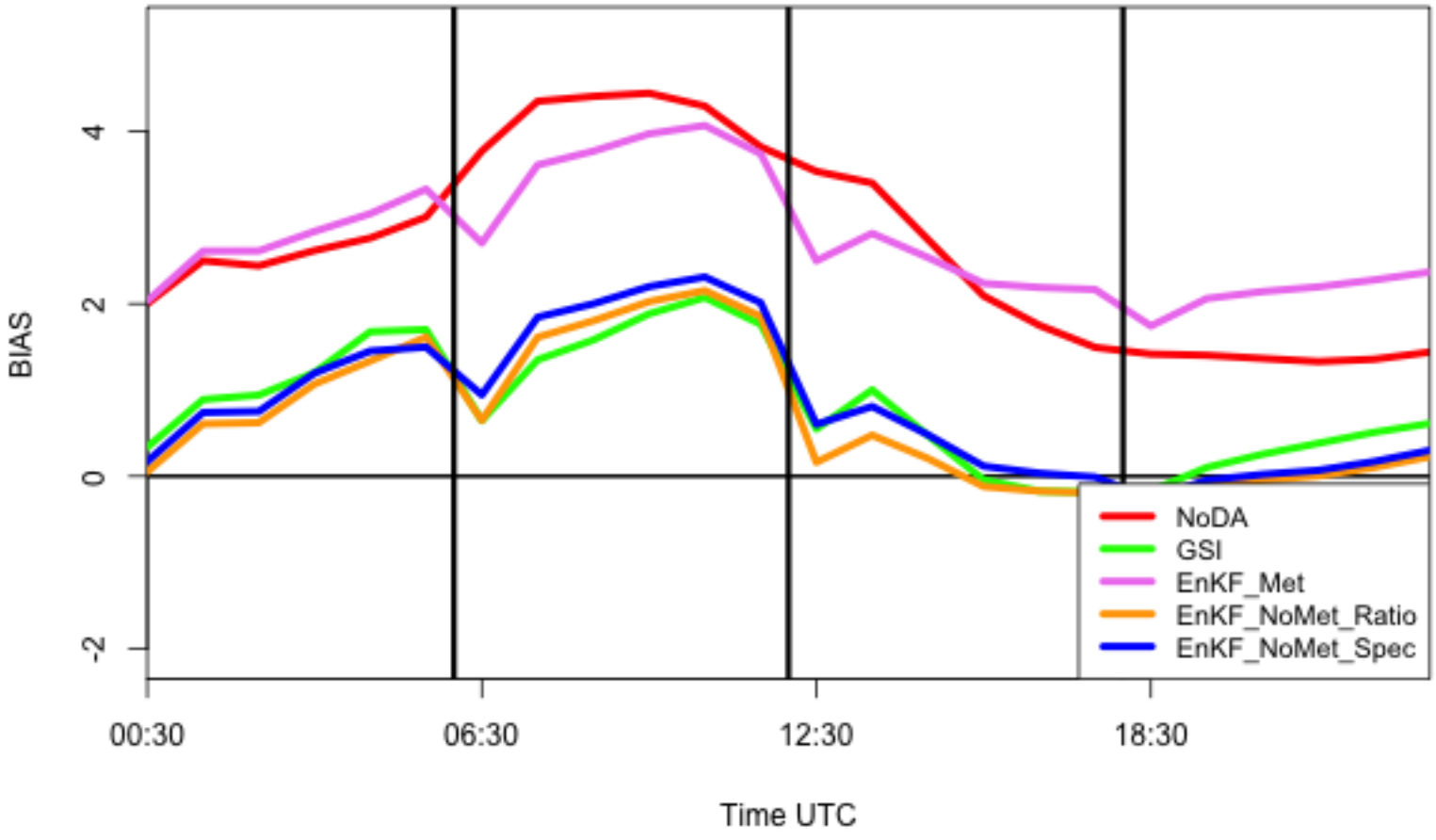
Evaluation

Model and observations are matched at a given forecast time over the domain (bias, pattern RMSE, spatial correlation).

Pattern RMSE (debiased RMSE, Taylor 2001)

$$E' \equiv \left[\frac{1}{N} \sum_{n=1}^{N} \left[\left(f_n - \overline{f} \right) - \left(r_n - \overline{r} \right) \right]^2 \right]^{\frac{1}{2}}$$

Evaluation – total PM2.5



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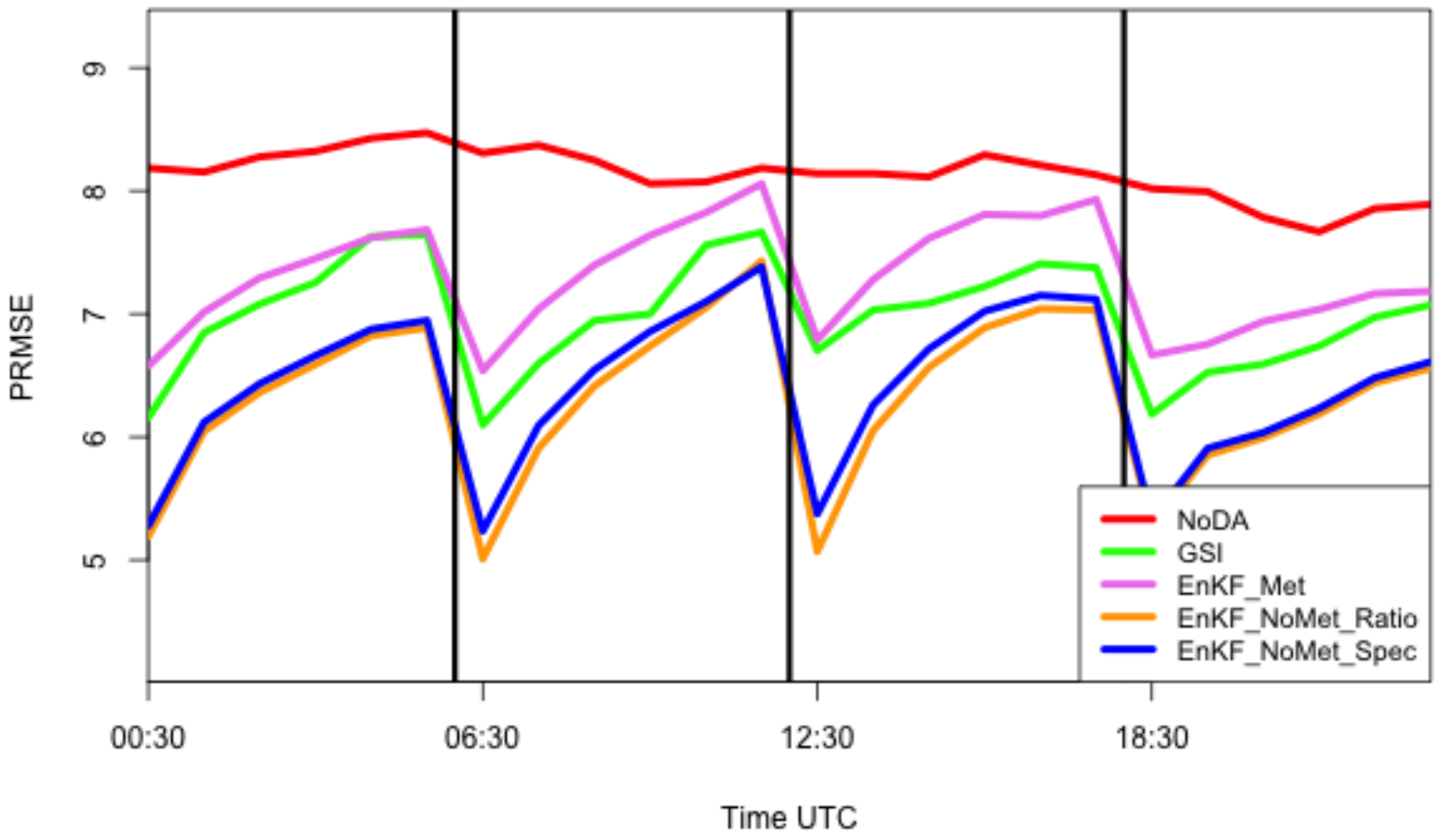

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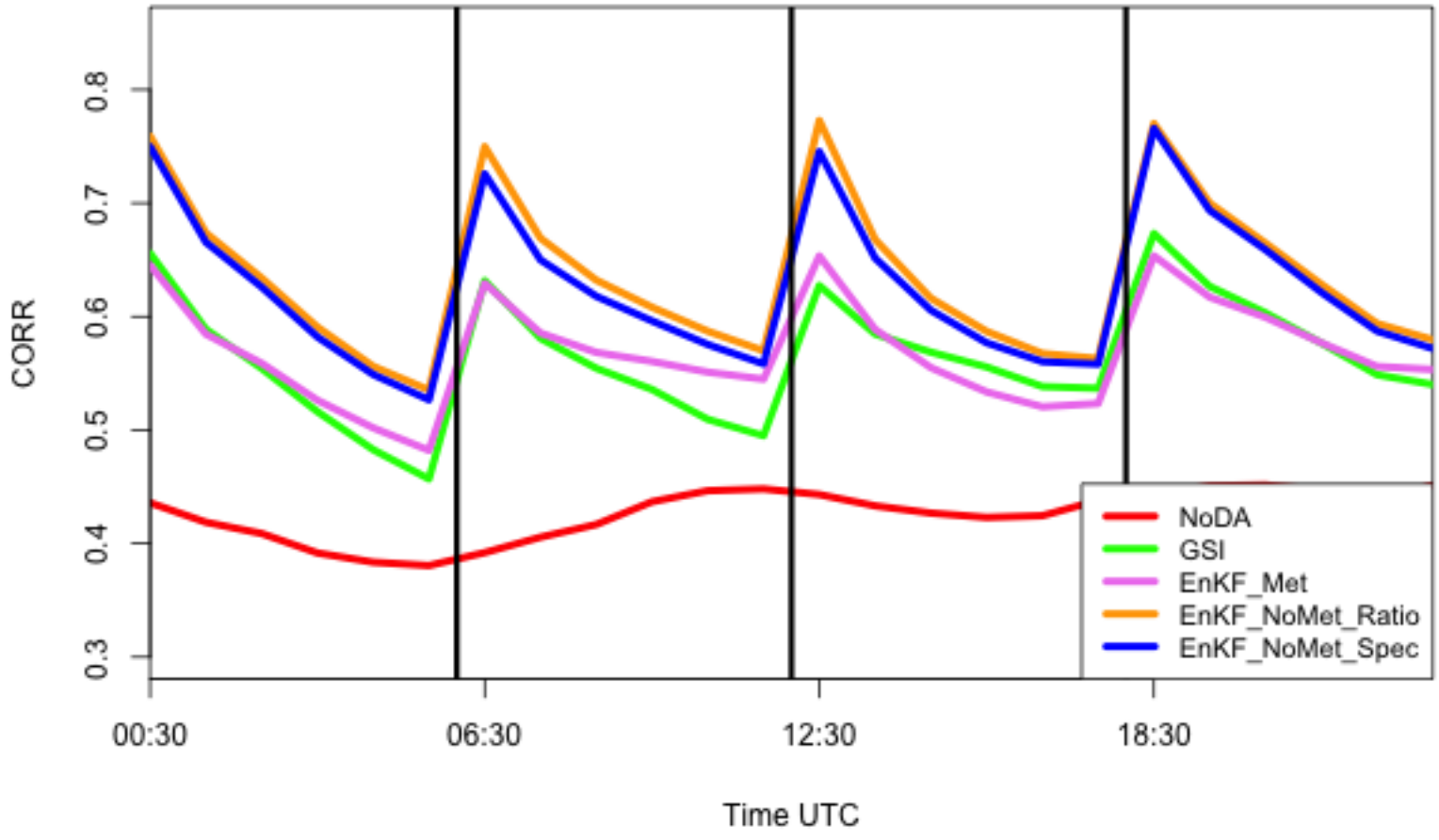
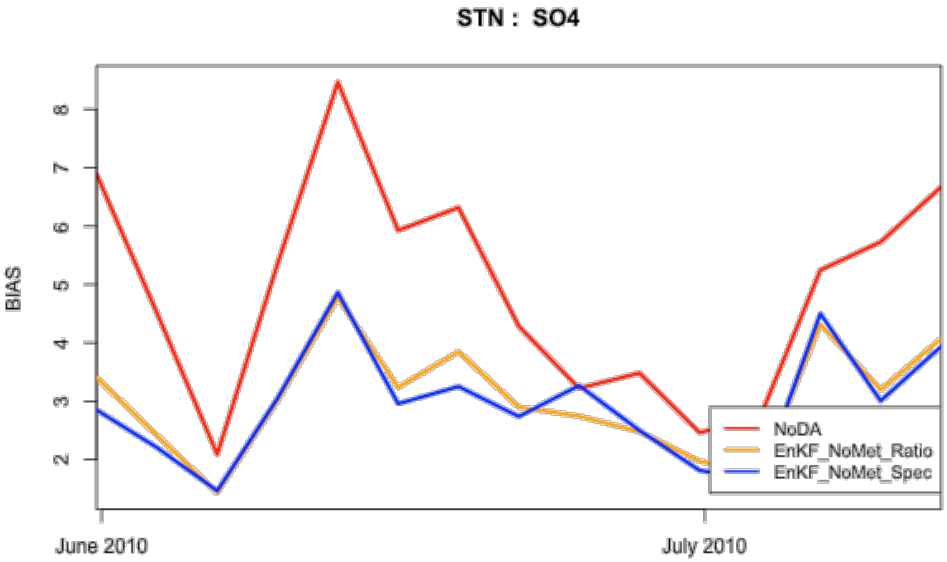
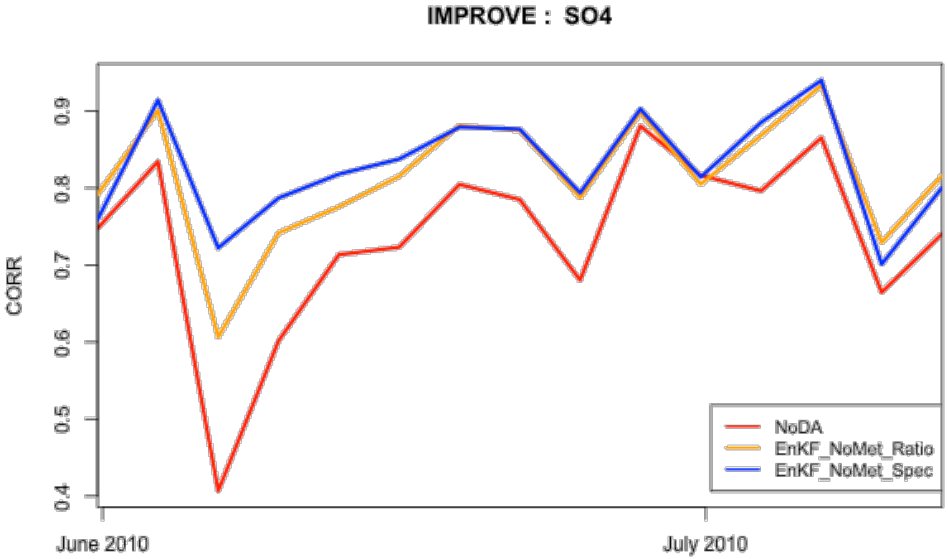
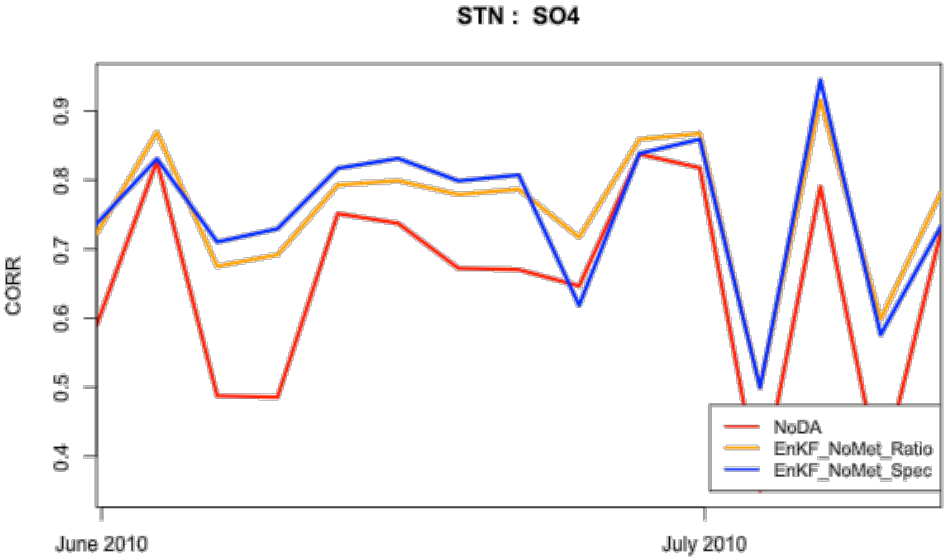


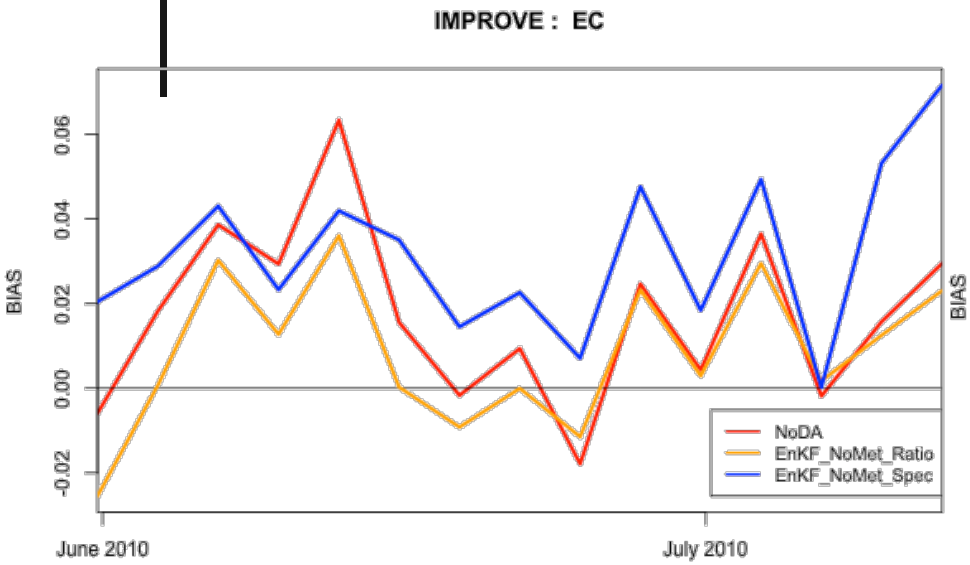
Evaluation SO4 (24-hr averaged measurements available every 3 days)

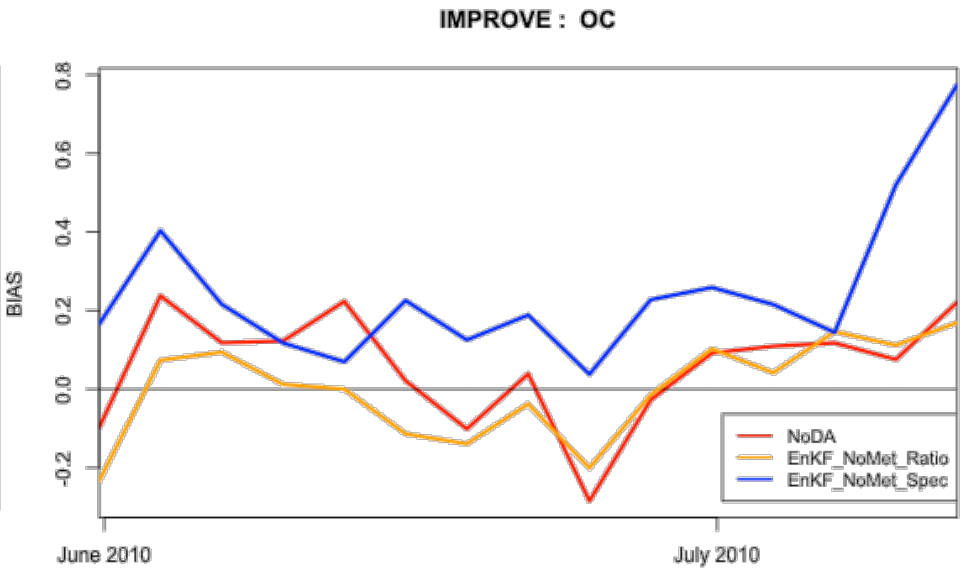


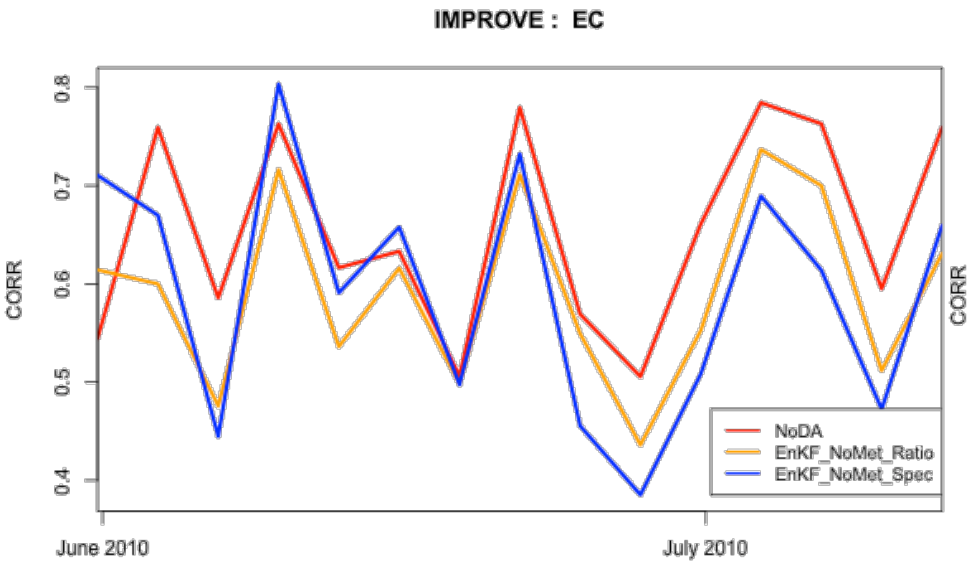


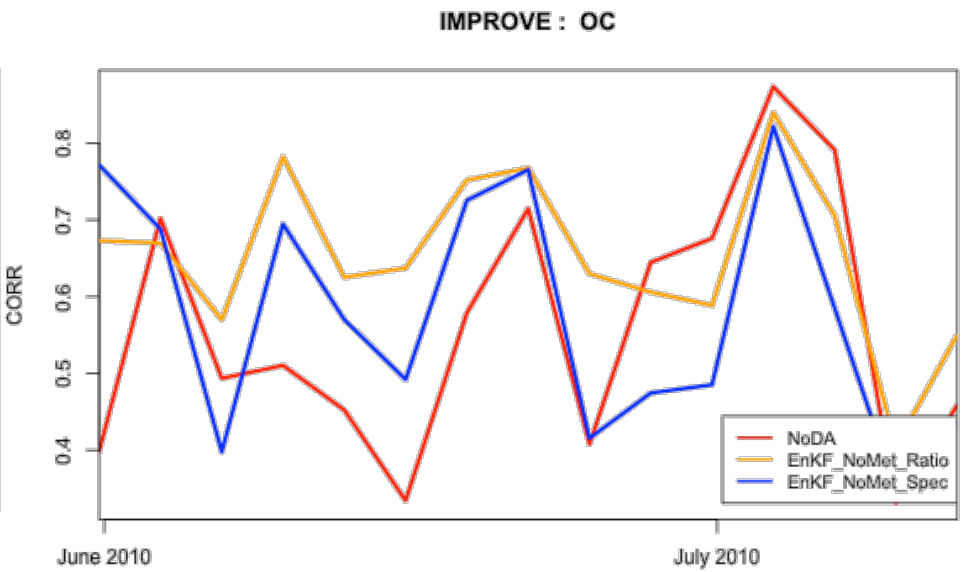


Evaluation EC/OC (24-hr averaged measurements available every 3 days)









Conclusions

- Verification statistics for EnKF vs. GSI clearly superior for the former in terms of total PM2.5 mass.
- Assimilation not necessarily positive impact in terms of aerosol species: that is because only total PM2.5 assimilated so results completely dependent on the model.
- No clear advantage when ensemble filter determines speciation compared to a priori ratios; as above: relations between species from model not necessarily reliable.
- Negative effect of meteorology/aerosol regressions derived by the filter;

two main reasons:

a) model builds up high aerosol concentrations above PBL since no observations available leading to lack of constraint on concentrations – possibly counteract this effect with satellite observations;

b) model can have skewed relationship between aerosols and meteorology.

- Assimilation of surface temperature, specific humidity, and wind unsatisfactory due to small spread of the ensemble in the PBL. Potential for large improvement of forecasts since surface meteorological observations plentiful but poorly assimilated.