Assimilation of Fine Aerosols using WRF-Chem and Ensemble Kalman Filter

Mariusz Pagowski ¹
Georg A. Grell ¹
Judith Berner ²
Kate Smith ²
Ming Hu ¹

¹- NOAA/ESRL, ²- NCAR
General

- PM2.5 is the single most critical factor affecting human mortality due to air pollution.
- Interdependence of meteorology and atmospheric chemistry: e.g. aerosols affect radiation and microphysics; improved model aerosols have a potential to positively influence meteorology but in short term forecasts currently do not (see J. Fast talk Monday).
- Because of this interdependence assimilation of chemistry has a potential to improve assimilation of meteorology via regression either in VAR or EnKF and vice versa; e.g. high tropospheric ozone from tropopause folds correlate with PV; also, surface ozone, PM2.5 correlate with mid-tropospheric streamfunction; correlations met-ozone are stronger than met-aerosols.
- As yet the potential largely unrealized because of the weaknesses of chemical forecasts and parameterizations of chemistry-met interactions.
Challenges for aerosol forecasting/assimilation

- Scarcity of in-situ observations of aerosols and precursors in the vertical; virtually, lack of observations of aerosol species anywhere; thus model verification and assimilation deficient by definition.
- Currently, satellite retrieval largely limited to AOD ie. a measurement of the extinction of light by aerosols in a vertical column; does not provide an independent information on aerosol species and vertical distribution since both based on model/climatology.
- Multiple state variables (in tens) which are correlated but correlations derived from model results not necessarily reliable.

I: Chemical initial state remains to a significant degree unknown.

- Results very much dependent on source emissions, error estimates in surface emissions 50-200%; also applies to forest fires.
- Chemical parameterizations have large uncertainties, more complex not always better.
- Air quality depends on meteorology in the boundary-layer where forecasts have poor skill: LSM+parameterizations+poor assimilation of surface meteorological observations. Also, clouds, rain – known to be poorly forecast.

II: Results strongly dependent on external forcings not only the initial state.
Dramatic improvements to

- the initial state considering available observations,
- chemical parameterizations,
- emissions inventories

not expected.

Possibly a chance to improve forecasts by parameterizing model/forcing errors
(in ensemble world conceptually straightforward but not necessarily leads to better results because the spread needs to be realistic to improve assimilation and forecasts)

- perturbation to emissions,
- stochastic parameterizations.
Challenges for aerosol forecasting/assimilation cont.

perturbations to emissions
- e.g. derive characteristic scale
- apply a recursive filter and multiply by random vector

stochastic parameterizations
- e.g. ECMWF’s SPPT (Stochastically Perturbed Parameterization Tendencies),
  \((dX/dt)_{new} = (dX/dt)_{old} \times (1 + \alpha), -1 < \alpha < 1,\)
- \(\alpha\) has a spatial pattern, varies in time as red noise (time correlation + random element)
- alternatively, can be applied to model parameters/forcings: e.g. deposition velocity, scavenging, extent/magnitude of forest fires, cloud fraction, SO\(_2\) to SO\(_4\) conversion – can be used to reduce model bias.
AIRNow network

- Total aerosol mass:
  - 1-hr average available round the clock;
  - urban, suburban, rural sites, unknown;
  - suitable for r-t assimilation.

IMPROVE and STN networks

- Aerosol species: SO4, OC, EC;
  - 24-hour averages every three days;
  - available after several weeks/months;
  - limited value for assimilation.

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;

June 1 - July 15, 2010
PM2.5 increment – examples

00 UTC

12 UTC
EnKF has a potential but not significantly better at higher computational cost
EnKF_Met vs. EnKF_no_Met

Time series of domain averaged PM2.5 concentration
(after five-day spin-up)

No_Met

Met
EnKF_Met vs. EnKF_no_Met

PM2.5 at model level 23 (~700mb)

No_Met

Geopotential perturbation

Met
Impact of EnKF assimilation at 20-km resolution – ten-day episode 2012

Bias

Corr

NoDA

EnKF
Impact of EnKF assimilation using different aerosol parameterization

June 2012

GOCART

More complex

bias

corr
Conclusions

- Large positive impact of assimilation on PM2.5, but fast error growth after the assimilation; from previous work: positive effect still present after 24 hours.
  - Some advantage of EnKF over GSI. Little impact of assimilations on individual aerosols species because observations of species not available for assimilation.
  - GOCART attractive because of simplicity, speed. Not deficient compared to more complex schemes nor other models (e.g. CMAQ).
  - Forecasts particularly poor over western NA (chemistry, fires, emissions).
  - Negative effect of EnKF regressions between meteorology and aerosols on forecasts.
  - Experiments with perturbed emissions have positive effect on assimilation and forecasts.
  - Experiments with stochastic parameterizations so far inconclusive.
  - In areas of dense surface observations effect of assimilating AOD minor. Potential where surface observations sparse.
  - Consider postprocessing to improve forecasts.