Urban air quality and regional haze weather forecast in Yangtze River Delta of China

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Outline

- Air pollution in Yangtze River Delta
- Urban air quality and regional haze weather forecast model
- Air quality forecast in urban
- Haze weather forecast in YRD
- Summary
Located on the western coast of the Pacific Ocean and covers an area of about 99,600 km², with a population of 75 million.
Heavy haze case 2008.10.27-29
Dust storm occurred in Mar. 20, 2010

昨天灰蒙蒙的大街上，南京市民多重‘装备’出行。

天津 20日，在今年首场明显扬沙天气影响下，市民冒着大风和沙尘走在街头。新华社

北京 扬尘天气里，几名游客在天安门广场上拍照。新华社
Continuous air pollution for more than 10 days
chemical weather forecasting (CWF) models

- **On line model**: SKIRON/Dust, WRF-Chem, ENVIROHRLAM, TAPM

- **Off line model**: ALADIN CAMx, CAMx-AMWFG, EURAD-RIU, FARM, LOTOSEUROS, MATCH, MM5-CAMx, MM5-CHIMERE, MM5/WRF-CMAQ, MOCAGE, NAME, OPANA, RCG, SILAM, THOR
  RegAEMS, NAQPS, PATH, TAQM
Urban air quality forecast system

WRF Preprocessing System

Automatic Download GFS Data

Emission Inventory

Weather processes simulation

Emission Preprocessing Model

Transport and diffusion

Weather processes simulation

Dry and wet deposition

Chemical reactions and aerosol process

Products Output

Hourly concentrations at selected sites

Hourly surface concentrations distribution, SO$_2$, NO$_2$, O$_3$,

Display and Release to Website

PM$_{10}$ Air Pollution Index

Previous forecast results

3-D grid chemical concentrations

Meteorological initial and Boundary conditions

Chemical initial and Boundary conditions

WRF-Chem Model

WRF-CHEM
Regional haze weather forecast system

WRF

RAEM

Emission Module
Transport Module
Chemistry Module
Diffusion Module
Deposition Module
Visibility Module

Gas Chemistry
Aerosol Chemistry
Aqueous Chemistry
Heterogeneous Chemistry
Dry Deposition
Wet Deposition

RegAEMS
Different aerosol schemes in RegAEMS

- $\text{SO}_4^{2-}, \text{NO}_3^-: \text{ISORROPIA (Nenes, 1998)}$
- EC, OC
- SOA: SORGAM (Schell, 2001)
- Sea salt: Monahan (1986)
- Dust: Gillette (1988)
Visibility scheme

\[ \nu = \frac{K}{b_{ext}} \quad (K \text{ is } 3.912) \]

\[ b_{ext} = b_{scat} + b_{abs} + b_{ag} + b_{sp} + b_{ap} \]

\[ b_{ext} = 3f(RH) \bullet \left( (NH_4)_2SO_4 + NH_4NO_3 \right) + 4\text{Organics} + 10\text{Soot} + \text{Soil} + 0.6\text{Coarsemass} + 0.175NO_2 + 10 \]
Haze level classification

- PM2.5 > 75 μg/m³
- RH < 0.8
- Visibility < 10 km

- Super heavy haze: Visibility < 2 km
- Heavy haze: 2 km ≤ Visibility < 4 km
- Medium haze: 4 km ≤ Visibility < 7 km
- Light haze: 7 km ≤ Visibility < 10 km
Air quality and haze weather forecast step

48 hours forecast with 16 hours spin up
Model settings for Shanghai forecast

- Horizontal grid: 4 nested domains
  - Domain 1: 88*75, 81km
  - Domain 2: 85*70, 27km
  - Domain 3: 76*67, 9 km
  - Domain 4: 88*73, 3 km
- Vertical level: 24 sigma level
- Model top: 100hpa
- Gas phase mechanism: RACM
- Aerosol: MADE/SORGAM
- Anthro. Emi.: INTEX-B + Shanghai emission inventory
- Natural Emi.: calculated online by Guenther scheme
Point source in Shanghai
Area source in Shanghai

- CO
- NOx
- SO2
- VOC
- PM2.5
- PM10
Line source in Shanghai

CO  NOx  SO2
VOC  PM2.5  PM10
SO₂ hourly concentration

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相关性 平均偏差

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偏差 相关性
## NO₂ Hourly Concentration

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### Table

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PM10 hourly concentration

- Observation
- Prediction (24-hour)

### Average

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<th>48-hour</th>
<th>48-hour</th>
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<td>60.69</td>
<td>65.73</td>
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<td>9.35</td>
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<td>77.63</td>
<td>84.76</td>
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<td>-1.22</td>
<td>6.27</td>
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### Monthly Average

- **Observed Average:** 78.90
- **Predicted Average (24-hour):** 77.63
- **Predicted Average (48-hour):** 84.76
- **Average Difference:** 0.20
- **Average Correlation:** 0.20
- **48-hour Difference:** -1.22
- **48-hour Correlation:** 6.27
Table 1

Monthly mean observed and predicted concentrations for three air pollutants averaged at 10 monitoring stations in Shanghai.

<table>
<thead>
<tr>
<th>Month</th>
<th>$\text{SO}_2$ ($\mu$g m$^{-3}$)</th>
<th>$\text{NO}_2$ ($\mu$g m$^{-3}$)</th>
<th>$\text{PM}_{10}$ ($\mu$g m$^{-3}$)</th>
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<tr>
<td>May, 2009</td>
<td>34.2</td>
<td>41.2</td>
<td>54.4</td>
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<td>Jun, 2009</td>
<td>31.2</td>
<td>34.9</td>
<td>48.5</td>
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<td>Jul, 2009</td>
<td>24.7</td>
<td>40.3</td>
<td>40.5</td>
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<td>Aug, 2009</td>
<td>21.0</td>
<td>35.3</td>
<td>32.3</td>
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<td>Sep, 2009</td>
<td>18.2</td>
<td>55.7</td>
<td>39.2</td>
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<td>Oct, 2009</td>
<td>28.1</td>
<td>60.3</td>
<td>56.9</td>
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<td>Nov, 2009</td>
<td>39.8</td>
<td>48.5</td>
<td>61.0</td>
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<tr>
<td>Dec, 2009</td>
<td>60.4</td>
<td>51.3</td>
<td>67.2</td>
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<td>Jan, 2010</td>
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<td>Mar, 2010</td>
<td>41.9</td>
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<td>Apr, 2010</td>
<td>23.1</td>
<td>36.4</td>
<td>46.1</td>
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<tr>
<td>Mean</td>
<td>33.3</td>
<td>43.2</td>
<td>50.0</td>
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Statistics on API prediction
Air quality forecast for 2nd Youth Olympic game in Nanjing in 2014

- **DOMAIN 1:** $88 \times 75$, 81 km
- **DOMAIN 2:** $85 \times 70$, 27 km
- **DOMAIN 3:** $70 \times 64$, 9 km
- **DOMAIN 4:** $55 \times 61$, 3 km
Meteorological variables in Nanjing during Oct., 2007
Observed and predicted concentrations of PM10, SO2 and NO2 in Nanjing during Oct., 2007
Table 2
Summary of partial API for three air pollutants and API averaged at 6 monitoring stations in Nanjing during Oct., 2007.

<table>
<thead>
<tr>
<th></th>
<th>PM$_{10}$</th>
<th>SO$_2$</th>
<th>NO$_2$</th>
<th>API</th>
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<td>OMV</td>
<td>80.80</td>
<td>52.73</td>
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<td>SMV</td>
<td>57.43</td>
<td>47.73</td>
<td>35.87</td>
<td>58.57</td>
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<td>D</td>
<td>23.37</td>
<td>4.90</td>
<td>8.23</td>
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<tr>
<td>R</td>
<td>0.34</td>
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<td>SD</td>
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<td>ARAQG</td>
<td>80%</td>
<td>60%</td>
<td>77%</td>
<td>80%</td>
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</table>

*OMV: Observed Mean Value, SMV: Simulated Mean Value, D: Deviation, R: Correlation Coefficient, SD: Standard Deviation, ARAQG: Accurate Rate of Air Quality Grade.*
Haze weather forecast in YRD using RegAEMS

Regional Center:
(32.06° N, 119.86° E)

Vertical level:
Vertical: 10 levels

Horizontal Grid Size:
DOMAIN 1: 88 × 75, 81 km
DOMAIN 2: 85 × 70, 27 km
DOMAIN 3: 70 × 64, 9 km

Prediction Period:
2009.1.1–2009.12.31
Observed vs. predicted meteorological variables

- Observed temperature (°C)
- Simulated temperature (°C)
- Observed wind speed (m/s)

Nanjing
R = 0.841

Observed RH (%)
Simulated RH (%)

Nanjing
R = 0.694

Shanghai
R = 0.807

Pudong
R = 0.607

Hangzhou
R = 0.722

Hefei
R = 0.820
Daily concentrations of PM10 and PM2.5 in YRD during 2009
Hourly visibility from observation and prediction in YRD during 2009
Daily RH, PM2.5, Visibility and Haze level forecast
Heavy haze case prediction
Backward trajectory, fire spot and biomass emission
Biomass burning

Fire spot

10月28日 18:00~20:00

RegAEMS

• OBSERVATION
• SIM. WITHOUT BIOMASS
• SIM. WITH BIOMASS

PM$_{10}$ (mg/m$^3$)

Data Assimilation in dust prediction

Directly analyze 3D aerosol mass concentration with a one-step procedure of variational minimization within the GSI

- Do NOT apply any assumption about vertical shape and relative weight of individual species.

\[ J(x) = \frac{1}{2} (x - x_b)^T B^{-1} (x - x_b) + \frac{1}{2} [y - H(x)]^T R^{-1} [y - H(x)] \]

- 14 WRF/Chem-GOCART 3D aerosol mass concentration as analysis variables
  - need background error covariance statistics for each aerosol species

- Use CRTM as the AOD observation operator, including both forward and Jacobian models

- In short, no much difference from 3DVAR DA for meteorological obs.
OMB/ OMA of MODIS AOD

(a) BIAS

(b) RMSE

Valid Time in March 2010 (UTC)
Summary

WRF-CHEM and RegAEMS are useful tools for urban quality and regional haze forecast.

- To improve the spatial resolution of emission inventory, especially emissions from fugitive dust, transportation and biomass burning in the Yangtze River Delta region, to improve the performance of model prediction.

- To include urban canopy model in the meteorological model to improve the performance of meteorology prediction.

- To improve the model performance of forecast on heavy air pollution case using data assimilation and satellite spot, such as dust storm, and biomass burning.