Development of the Chinese Chemical Weather Forecasting System – CUACE and its Application in AQ Forecasts

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Chemical Weather Forecast – 化学天气预报 → Air Quality (AQ) NRT (near real time) Data – 近实时数据
2011/10/29 A wide range of fog and haze
Development of the Chinese Chemical Weather Forecasting System – CUACE

建立化学天气预报
CMA Chemical Weather Forecasting System

- Geophysical data
- Meteorological obs.
- Population, Economical and land use data

**GRAPES/MM5 Meteorology Transport**

- Gas Phase Chemistry
- CAM (Canada Aerosol Module)
- ISORROPIA (Aerosol Equilibrium Scheme)
- Feedback Radiation, Cloud
- Data Assimilation

- SMOKE (Emission Scheme)
- O$_3$, CO, NO$_x$
- PM$_{2.5}$, PM$_{10}$, Acid Deposition
- NH$_4$, NO$_3$
CUACE
CMA Unified Atmospheric Chemistry Environment
Emission System

Inventories
- Energy Use
- Industries
- Agriculture
- Forests
- Waste Treatment

Processor
- Geophy, GPS
- Emission Profiles
- SMOKE

Total Emissions
Point Emission System
Area Emission System

Gridded Emissions
Gridded Emissions

Total: 1.4 Tg/a
Unit: t/km²

Total: 2.95 Tg/a

BC

OC
CUACE/Gas

Chemical Mechanism: radm2

- 66 Species, 5 SOA;
- 21 Photochemical reactions, 141 gas phase chemical reactions;
- A simplified SOA formation scheme;
- On-line dry and wet depositions.
Sectional Aerosol Approach

\[ \frac{dN_i}{dt} = I_i - k^* I_{k^*} - N_i \sum_{i=k^*}^{\infty} \beta_{ii} N_i \]

\[ \frac{dN_{k^*}}{dt} = I_{k^*} - \beta_{i,k^*} N_{i,1} N_{k^*} - N_{k^*} \sum_{i=k^*}^{\infty} \beta_{k^*,i} N_{k^*} N_i \]

\[ \frac{dN_k}{dt} = \beta_{1,k-1} N_i N_{k-1} + \frac{1}{2} \sum_{i=k^*}^{k-1} \beta_{i,k-1} N_i N_{k-1} - \beta_{i,k} N_i N_k - N_k \sum_{i=k^*}^{\infty} \beta_{i,k} N_i \] (\(k > k^*\))

Gong et al. 2003
CUACE/Aero

Aerosol Dynamics
- Clear Sky

Dry Deposition
Sulphur Chemistry
Nucleation
Condensation
Coagulation

OH, NO₃, O₃, HNO₃
Gas Chemistry Module

Gas H₂SO₄

Condensation

Nucleation

[5,7]

Coagulation

κ

Ambient size

Aerosols

r_c

Clouds
Challenges in AQ Forecasts

- High concentrations with complex chemical compositions;
- Rapid changes in economy and hence difficulty to obtain timely emissions;
- Inaccurate statistics for emission inventory establishment;
- Modeling limitations and uncertainties.
Feature of Chinese Aerosols

Zhang et al. 2011

2006 and 2007.14 CAWNET stations, 24-h Data

CMA China Atmosphere Watch Network (CAWNET) Observation

Associated with two National 973 Projects "Aerosol and its Climate Effects" "Aerosol – Cloud – Asian Monsoon"
Model Predictions – CUACE

NANJIAO

Good

Bad

Weather Forecast not correct
Wind speed too high

Zhou et al. 2011
Model Predictions – CMAQ

An et al. 2011
Improvement – 1

Acquiring Near Real Time Data
CAWNET
CMA Atmospheric Watch Network

CMA China Atmosphere Watch Network (CAWNET) Observation

PM10
PM2.5
BC
CARSNET
CMA Aerosol Remote Sensing Network

AOD
Satellites - AOD

FY-3A

MODIS
Product

An on-line NRT data collection system for data assimilations and model evaluations
Improvement – 2

Data Assimilation using NRT Data
3D-Var Method

3D-Var is to minimize the following function (Lorenc, 1986):

\[ J(x) = \frac{1}{2} \left[ (x - x_b)^T B^{-1} (x - x_b) + (H(x) - y_o)^T O^{-1} (H(x) - y_o) \right] \]

Using the observational data \( y_0 \) to find the solution of \( x \) that satisfies the min \( J(x) \rightarrow x_a \)
Dust Storm: CUACE/Dust

Satellite
FY-2C 2D

Ground Obs.

SDS Observations

Data Assimilation

CUACE/Dust

Gong and Zhang 2008, ACP
Comparisons of CUACE/Dust forecasting results for 10 April 2006 with and without data assimilation. The symbols of “S”, “$”, “§”, “&” indicate floating dust, blowing dust, SDS, severe SDS, respectively, obtained from surface meteorological stations of CMA.
SDS Assimilation Results - 2

Data Assimilation $\rightarrow$
TS – 0.31

Nu et al. 2008, ACP

$\leftarrow$ No Data Assimilation
TS (Threat Score) – 0.22
AOD (FY-3A) Assimilation

Satellite

Corrections

Initial

Final

2009-9-29
Aerosol Feed back on weather

Wang et al. 2011 JGR
Product

An AQ forecasting system with data assimilation capacity using the NRT time in China.
Improvement – 3

Inverse Modeling of Emissions
CMA Chemical Weather Forecasting System

- **Emissions**
- **GRAPES/MM5** (Meteorology Transport)
- **Gas Phase Chemistry**
  - $O_3$, CO, NOx
  - PM$_{2.5}$, PM$_{10}$, Acid Deposition
- **CAM** (China Aerosol Module)
- **ISORROPIA** (Aerosol Equilibrium Scheme)
- **Feedback Radiation, Cloud**
- **Data Assimilation**

Geophysical data, Meteorological obs.
(1) Adjoint Model

Inverse Model

Parameter Estimate
\[ p = p_0 \]

Forward Model
\[ t_0 \rightarrow t_f \]

Cost function
\[ J \sim (\text{model-obs})^2 \]

Improved Estimate
\[ p = p \]

Optimization

Adjoint Model
\[ t_f \rightarrow t_0 \]

Adjoint Forcing
\[ \frac{\partial J}{\partial c(x, t)} \]

Gradients (sensitivities)
\[ \lambda = \nabla_p J \]
(2) Ensemble Kaman Filter Model

EnKF
BC Conc. (μg m$^{-3}$)

- **Forecasted**

- **Observations:**
  - Beijing: 7.0
  - Xi’an: 0.09
  - Lin An: 1.03
BC Emission Strength (µg m\(^{-2}\) s\(^{-1}\))

Original

After Adjustment
BC Conc. \( (\mu g \ m^{-3}) \)

Original Forecasting

After Adjustment

Beijing: 7.0, Xi’an: 0.09, Lin An: 1.03
Product

An emission inventory that combines the bottom-up approach with the inversed modeling emissions, that can get better AQ forecasting results.
Before and during the Beijing Olympic Games, the CMA provided 2-day forecasts of PM10, visibility and O3 to BMG and subsequently provided to Beijing Meteorological Bureau (BMB) and Beijing Municipal Environmental Protection Bureau (BMEPB).
Visibility Forecast for National 60th anniversary
参加了国家级团队的60周年大庆预报服务
Comparison between Forecasted and Observed Visibility

\[ r = 0.65, \text{ 绿线: 模拟, 蓝线: 观测} \]
Conclusions

• A chemical weather forecasting system has been developed within the Chinese weather forecasting model - GRAPES.

• The NRT data can be used to improve the accuracy of the AQ forecasts through the data assimilation for the realistic initial conditions and inverse modeling for a timely and accurate emissions.

• Chemical weather forecast can not only forecast AQ but also improve the conventional weather forecasts through the feedback of aerosols.
Thank you!