Current status and updates of the aerosol forecast in Japan Meteorological Agency

Taichu Y. Tanaka¹, Tsuyoshi T. Sekiyama¹, Takashi Maki¹, Mizuo Kajino¹, and Kazutaka Yamada²

¹Meteorological Research Institute,
²Japan Meteorological Agency

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Topics

• Current aerosol (and air quality) forecasting in JMA
• Update of the global aerosol model
• Development of the regional aerosol/air quality model (NHM-Chem)
• Data assimilation
  – OSSE and validations with MET/MODE
  – Inverse analysis of dust emission flux
Current aerosol and air quality forecasting in JMA
Operational aerosol and air quality models in JMA

KOSA (Aeolian Dust) Prediction

Aerosol model

Chemistry Climate Model

Numerical Model

Photochemical oxidant information for the whole of Japan (in Japanese)
KOSA (Aeolian Dust) information

- JMA operates a numerical dust model for the prediction of Kosa.
- The forecast charts up to 3 days ahead (96 hour) with the interval of 6 hours are updated everyday.
- Two kinds of information are provided.
  - Concentration between the surface to the height of 1 km.
  - Total amount from the surface to the top of the atmosphere.

Asian dust event: 21 March 2010
## Specifications of operational aerosol model in JMA

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<th>Details</th>
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<td>Mellor-Yamada level-2 closure</td>
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<td>30 levels (surface – 10 hPa): for meteorology</td>
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<td>Dust emission</td>
<td>- Size-bin method: 10 size classes (i.e. dust particles diameters: 0.2-20µm)</td>
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<tr>
<td></td>
<td>- A global soil texture database for the size distribution of parent soils</td>
</tr>
<tr>
<td></td>
<td>- Erodibility factor for vegetation cover, snow cover, land-use type and soil type</td>
</tr>
<tr>
<td>Dry and wet deposition</td>
<td>Depend on dust particle size</td>
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</table>
Update of the global aerosol model
Development of our new global aerosol model

• We are now developing our new global aerosol model **MASINGAR mk-2**, for both
  — aerosol forecasting and
  — climate research.

• The aerosol model is a part of the Earth System Model of Meteorological Research Institute, **MRI-ESM1**, and coupled using a coupler library **Scup**.

• New and sophisticated physical processes.

• Aims to be computationally efficient.
Aerosol model MASINGAR mk-2
(Model of Aerosol Species in the Global Atmosphere)

• Five aerosol species are included:
  – Sulfate, black carbon, organic carbon
  – Sea salt, and Mineral dust
    • Particle size distributions are expressed by sectional approach (6-bins from 0.2 to 20 μm)
    – Depending on purposes, volcanic ash, radioactive materials

• The emission flux of mineral dust, sea-salt, and dimethylsulfide are calculated based on the surface properties calculated by the atmospheric model, MRI-AGCM3.
The MRI Earth System Model

- The MRI-ESM1 aims to improve the prediction of global warming.

- The model components are connected using a coupler library called **SCUP**, which couples each model using Message Passing Interface (MPI).
The Coupler Library, Scup

- Scup (Simple coupler) is a simple and easy-to-use general-purpose coupler for coupling component models.
  - Efficient data exchange by direct communication via Scup library among the processes of the component models.
  - Different coordinates/grids can be used in each component model by supporting 2-dimensional and 3-dimensional coordinate/grid transformation among the models.
  - All written in Fortran 95 and therefore easy to be compiled.
  - Flexible configuration of coupling with namelist file.

(Yoshimura and Yukimoto, 2008)
# Update of aerosol forecasting model

<table>
<thead>
<tr>
<th></th>
<th>Current operational global dust forecast model</th>
<th>Next global aerosol model</th>
</tr>
</thead>
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<tr>
<td>Global aerosol model</td>
<td>MASINGAR (Tanaka et al. 2003)</td>
<td>MASINGAR mk-2 (Tanaka et al., manuscript in preparation)</td>
</tr>
<tr>
<td>Dust emission</td>
<td>Function of 10m wind speed ( F = C u_{10}^2(u_{10} - u_t) )</td>
<td>Function of surface friction velocity (Shao et al., 1996; Tanaka and Chiba, 2005)</td>
</tr>
<tr>
<td>Included aerosol species</td>
<td>Mineral dust</td>
<td>Mineral dust, sulfate, BC, OC, sea salt</td>
</tr>
<tr>
<td>Model grid resolution</td>
<td>Horiz. T106 (Approx. 1.125°) Vertical 20 layers</td>
<td>Horoz. TL159 → TL319 (0.56°) Vertical 40 or 48 layers</td>
</tr>
<tr>
<td>Atmospheric model</td>
<td>MRI/JMA 98 AGCM (Shibata et al., 1998)</td>
<td>MRI-AGCM3 (Yukimoto et al., 2012)</td>
</tr>
<tr>
<td>Advection</td>
<td>3-dimensional semi-Lagrangian</td>
<td>✓</td>
</tr>
<tr>
<td>Convective transport</td>
<td>Arakawa-Schubert</td>
<td>Tiedtke-like scheme</td>
</tr>
<tr>
<td>Land surface model</td>
<td>3-layer Simple Biosphere</td>
<td>HAL</td>
</tr>
<tr>
<td>Coupling of aerosol model with AGCM</td>
<td>Subroutine call in each time step</td>
<td>Connected using SCUP library (Yoshimura and Yukimoto, 2008)</td>
</tr>
</tbody>
</table>
Quick comparison

MASINGAR
27 April 2012 00UTC MASINGAR Forecast t+006 VT: UTC
Total Aerosol Optical Depth at 550 nm

MASINGAR mk-2
27 April 2012 00UTC MASINGAR Forecast t+006 VT: UTC
Total Aerosol Optical Depth at 550 nm

NAAPS
Friday 27 April 2012 00UTC NAAPS Forecast t+006
Friday 27 April 2012 06UTC Valid Time
Total Aerosol Optical Depth at 550 nm

MACC
Friday 27 April 2012 00UTC MACC Forecast t+006
Friday 27 April 2012 06UTC Valid Time
Total Aerosol Optical Depth at 550 nm
Development of the regional aerosol/air quality model (NHM-Chem)

Motivation

• Operational Forecast:
  For more detailed forecast in finer resolution, regional chemical transport model (CTM) is desirable.

• Research activity:
  It is desirable to include physically and chemically complicated processes, such as aerosol microphysical kinetics and cloud processes, with finer resolution.

• ➔ Development of regional scale CTM.
NHM-Chem: A CTM with JMA NHM

• JMA has a meso-scale model called NHM (Non-Hydrostatic Model) for operational weather forecast and meteorological research.

• Our development plan: Develop a CTM that work with JMA NHM ➔ NHM-Chem

Satellite IR Image

Simulated accumulated water content by NHM (Saito et al. 2001)
Category approach: List of aerosol tracers

<table>
<thead>
<tr>
<th>Category name</th>
<th>Physical components</th>
<th>Chemical compositions</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATK</td>
<td>M₀ M₂</td>
<td>OA SO₄²⁻ NH₄⁺ NO₃⁻ Cl⁻ H₂O</td>
</tr>
<tr>
<td>ACM</td>
<td>M₀ M₂</td>
<td>UID OA SO₄²⁻ NH₄⁺ NO₃⁻ Cl⁻ H₂O</td>
</tr>
<tr>
<td>AGR</td>
<td>M₀ M₂</td>
<td>UID BC OA SO₄²⁻ NH₄⁺ NO₃⁻ Cl⁻ H₂O</td>
</tr>
<tr>
<td>COR</td>
<td>M₀ M₂</td>
<td>UID BC OA DU SS SO₄²⁻ NH₄⁺ NO₃⁻ Cl⁻ H₂O</td>
</tr>
</tbody>
</table>

IOC & SOA → POA → Soot → seasalt

Gas chem. (SAPRC99), NPF (Kuang), SOA (CMAQ-AE5), Aqueous chem. (RADM)

4-7 categories are used for the 3-D simulation (SS, DU, POL)

MADMS: 3 moment bulk aerosol dynamics model.
MBHM: a box model simulation using 64 bins

Banana curve cannot be resolved using a single modal approach
Aerosol and cloud microphysics

- Nucleation: Kuang et al. (2008)
- Condensation: Kajino (2011)
- Coagulation: Kajino (2011)
- IN activation: Lohmann and Diehl (2010)
- Cloud microphysics: Lin et al. (1983)

Aerosols category based on formation mechanisms
Size distribution of each category characterized as uni-modal LNSD.
Modeling aerosol chemistry, size and mixing type

- **PM2.5/PM10 ratio at Jeju**
  - The ratios are 0.9, 0.67, and 0.5 for SO4, NO3, and Na both in observation and simulation.

- **PM1/TSP ratio at Hedo**
  - SO4 is ~1, NO3 is <0.1

- **Mixing type at Jeju**
  - 60% of nitrate with sea salt

- **Mixing type at Hedo**
  - >90% of nitrate with sea salt

- **Nitrate mixed with soot [%]**
  - (affect optical property)

- **Nitrate mixed with sea salt [%]**
  - (not affect very much)
Data assimilation: OSSE and validations with MET/MODE

T. T. Sekiyama, T. Y. Tanaka, T. Miyoshi (U. Maryland), will be submitted to GMD.
EnKF for aerosol analysis

The CALIPSO orbit has an about 1000 km longitudinal interval per day at mid-latitudes.

Lidar view angle: almost zero...

Data density: very sparse horizontally...

But it has vertical profiles.
EnKF for aerosol analysis


Ground-based lidar network (NIES AD-Net): NIES Japan is operating more than 20 lidar stations in East Asia.
EnKF for aerosol analysis

Observation Variables:
- attenuated backscattering coeff. at 532 nm;
  a) CALIPSO/CALIOP;
  b) model without data assimilation;
  c) model with data assimilation.

White squares: aerosol plumes.

Sekiyama et al., ACP (2010)
EnKF for aerosol analysis

Contours and gray shades are **surface dust concentrations**.

(a) Free model-run result without data assimilation.
(b) CALIPSO data assimilation result.

Red and blue circles are weather stations. The **Red ones observed aeolian dust** on the day. Blue ones did not observe any dust events.

Sekiyama et al., ACP (2010)
What is an OSSE?

- OSSE: Observation System Simulation Experiment
  - Evaluation of data assimilation technique
  - Optimization of observation network
  - Investigation of the impact of new observation data

- OSSE is an experiment in virtual world
  - True value and observational error is KNOWN because the model simulations make the virtual world.
  - Because the true value is known, checking of answers can be done

(In the real world, we cannot really know the true values or observational errors.)
What is the virtual world of OSSE?

Virtual Earth produced by the numerical model

If CALIPSO is working in this virtual space...

Producing cloud noises is not easy!

The atmosphere should be observed like this.
Making simulated observation data

1. Run the model freely with slightly different boundary conditions
   1) Modify the dust emission scheme
   2) Use different emission inventory of SO₂
   3) Change the time constant of nudging time constant of atmospheric field.

2. Calculate the attenuated backscatter using the observation operator (observation simulator)
   ✖ Required variables: Cloud amount, aerosol concentration, air temperature, pressure, and humidity

3. Add observational error (random noise).
Assimilate to the virtual observation

True value (from which virtual observations are made)

Free-run with different boundary condition

Data assimilated distribution using EnKF

Optical depth of mineral dust (31 May 2007)
Limitation of the classical evaluation index

We want to know the shape and location of the aerosol plume.

Optical depth of mineral dust (31 May 2007)
Application of MODE/MET to the evaluation of the data assimilation
Object-based evaluation (MODE)

- We used the Method for Object-Based Diagnostic Evaluation (MODE) in Meteorological Evaluation Tool (MET).
  - Recognize the similar distribution with smoothing and pattern matching
  - Compare the attribute of each clusters
  - Quantify the similarities of the clusters
- Source code of MODE is available for WRF
  - Used for validation of precipitation forecast (NCAR)
- Question: Is it applicable to the diagnostics of aerosol distribution?
Background and Motivation

Which forecast is better?

(a) O A

(b) O A

(c) O A

(d) O A
Example Single Attributes

Centroid  Axis  Convex Hull
MODE analysis of dust: Before data assimilation

True

Free-run with different boundary conditions

Cent. Dist = 1.07 grids
Area Ratio = 0.54
50% Int. Ratio = 0.95

Optical depth of mineral dust (31 May 2007)
MODE analysis of dust: After data assimilation

True

Data assimilated result with EnKF

Optical depth of mineral dust (31 May 2007)
Evaluation using MODE: Dust

- Averaged centroid distance of dust aerosol AOD in East Asia
Evaluation using MODE: Dust

Dust Plumes: Lat 20ºN-57.5ºN Lon 70ºE-162.5ºE

Area Ratio

01 08 15 22 29 05 12 19 26 03 10 17 24 31
March April May

Free-Model Run!
Data Assimilation!

Better

• Averaged area ratio of dust aerosol AOD in East Asia
Evaluation using MODE: Dust

- Averaged intensity ratio of dust aerosol AOD in East Asia
Sensitivity study of the frequency of CALIPSO observation

The data assimilation results become better with 4 CALIPSO satellite into different orbit.

Total dust emission: 1 satellite
Total dust emission: 4 satellite
Summary of OSSE of CALIPSO/CALIOP

- The EnKF data assimilation system with satellite lidar worked well in a simulated virtual atmosphere.
- It is possible to conduct data assimilation with the attenuated backscatter.
  - Available without retrieval
- Data assimilation is possible with sparse in horizontal but dense in vertical and temporal data.

Effectiveness of satellite lidar observation
- satellite-borne lidar can be effective with data assimilation.
- OSSE experiment will make it possible to evaluate the future satellite-borne lidar (such as JAXA/EarthCARE: 2015).
Inverse analysis of dust emission flux

T. Maki, T. T. Sekiyama, T. Y. Tanaka
Inverse analysis of dust emission flux using EnKF

Sekiyama et al., SOLA (2011)
Inversion analysis of dust emission using Bayesian synthesis

- Inversion analysis by Bayesian synthesis method is applied to dust emission in Asia.
  - More talk on Wednesday.
Comparison of inverse analyses of dust emission

Model estimation

Data assimilation

Correction=(b)−(a)

Comparison of the inversion analyses with the same model (MASINGAR) using different method: EnKF with CALIOP versus Bayesian synthesis with surface PM10.

⇒ The tendencies are qualitatively consistent.

Inversion may be difficult because of the long distance from surface observations.

Sekiyama et al., SOLA (2011)

Maki et al., SOLA (2011)
This is the end of the presentation.

Thank you very much!

Grazie mille.