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

Taichu Y. Tanaka[1], Tsuyoshi T. Sekiyama[1], Takashi Maki[1], Mizuo Kajino[1], and Kazutaka Yamada[2]

[1.] *Meteorological Research Institute,*
[2] *Japan Meteorological Agency*

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# Topics

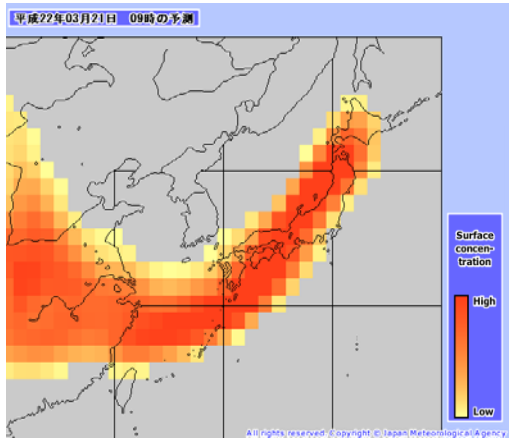
- Current aerosol (and air quality) forecasting in JMA
- Update of the global aerosol model
- Development of the regional aerosol/air quality model (NHM-Chem)
- Data assimilation
  - OSSE and validations with MET/MODE
  - Inverse analysis of dust emission flux

# Current aerosol and air quality forecasting in JMA

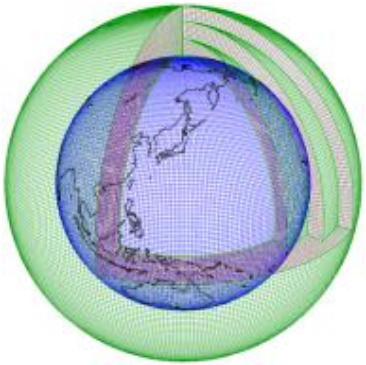
# Operational aerosol and air quality models in JMA

**KOSA (Aeolian Dust) Prediction**

http://www.jma.go.jp/en/kosa/




**Aerosol model**



**Numerical Model**

**Chemistry Climate Model**

**photochemical oxidant information for the whole of Japan (in Japanese)**

全般スモッグ気象情報□第１号
平成○○年○○月○○日□□時□□分□気象庁予報部発表

－光化学オキシダント－

（見出し）
□関東地方や九州北部地方（山口県を含む）の一部の地域では、今日（○○日）昼頃から夕方にかけて、光化学スモッグの発生しやすい気象状態となるでしょう。
□九州北部地方（山口県を含む）では、明日（△△日）も光化学スモッグの発生しやすい気象状態となる見込みです。

（本文）
□関東地方や九州北部地方（山口県を含む）の一部の地域では、今日（○○日）昼頃から夕方にかけて、晴れて日照が多く、風速も平均３メートル程度と弱く、気温は３０度くらいまで上がる見込みです。

□このため、光化学スモッグの発生しやすい気象状態となるでしょう。

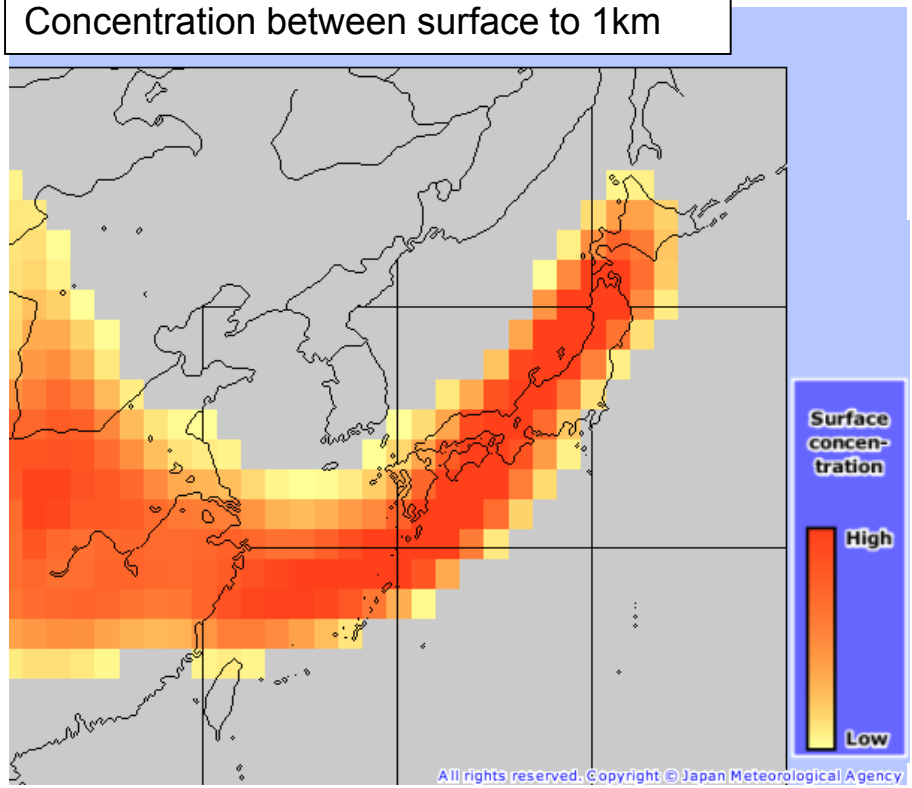
□九州北部地方（山口県を含む）では、明日（△△日）も晴れて気温が上がり、光化学スモッグの発生しやすい気象状態となる見込みです。

□屋外での活動に十分注意してください。

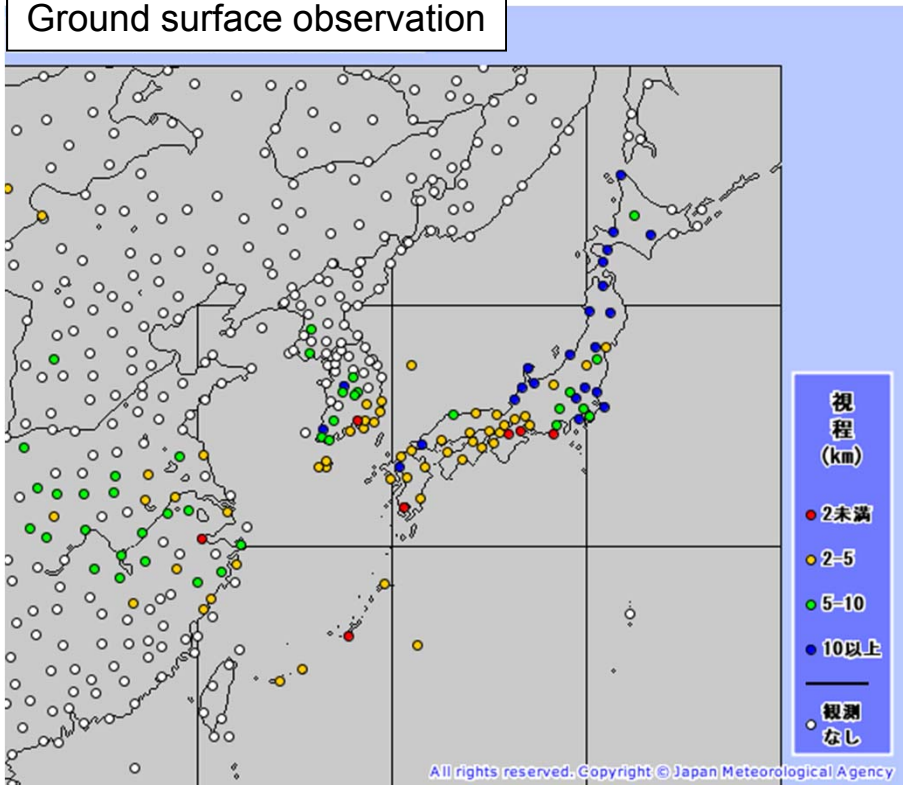
# KOSA (Aeolian Dust) information

- 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.

Concentration between surface to 1km




Ground surface observation




Asian dust event : 21 March 2010

# Specifications of operational aerosol model in JMA

| | |
|---|---|
| Basic equations | Eulerian model coupled with a GCM |
| Transport | 3D semi-Lagrangian transport |
| Vertical diffusion | Mellor-Yamada level-2 closure |
| Convective transport | Mass flux by Arakawa-Schbert moist convection scheme |
| Grid size | T106 (1.125°) |
| Vertical levels | 30 levels (surface – 10 hPa): for meteorology<br>20 levels (surface – 45 hPa): for aerosols |
| Initial time and forecast time | 96 hours from 12 UTC (once a day) |
| Forcing data (nudging) | Global analysis and forecasts of the JMA's operational Global Spectral Model (GSM) |
| | Snow depth analysis |
| Dust emission | - Size-bin method: 10 size classes ( i.e. dust particles diameters: 0.2-20μm)<br>- A global soil texture database for the size distribution of parent soils<br>- Erodibility factor for vegetation cover, snow cover, land-use type and soil type |
| Dry and wet deposition | Depend on dust particle size |

# 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.

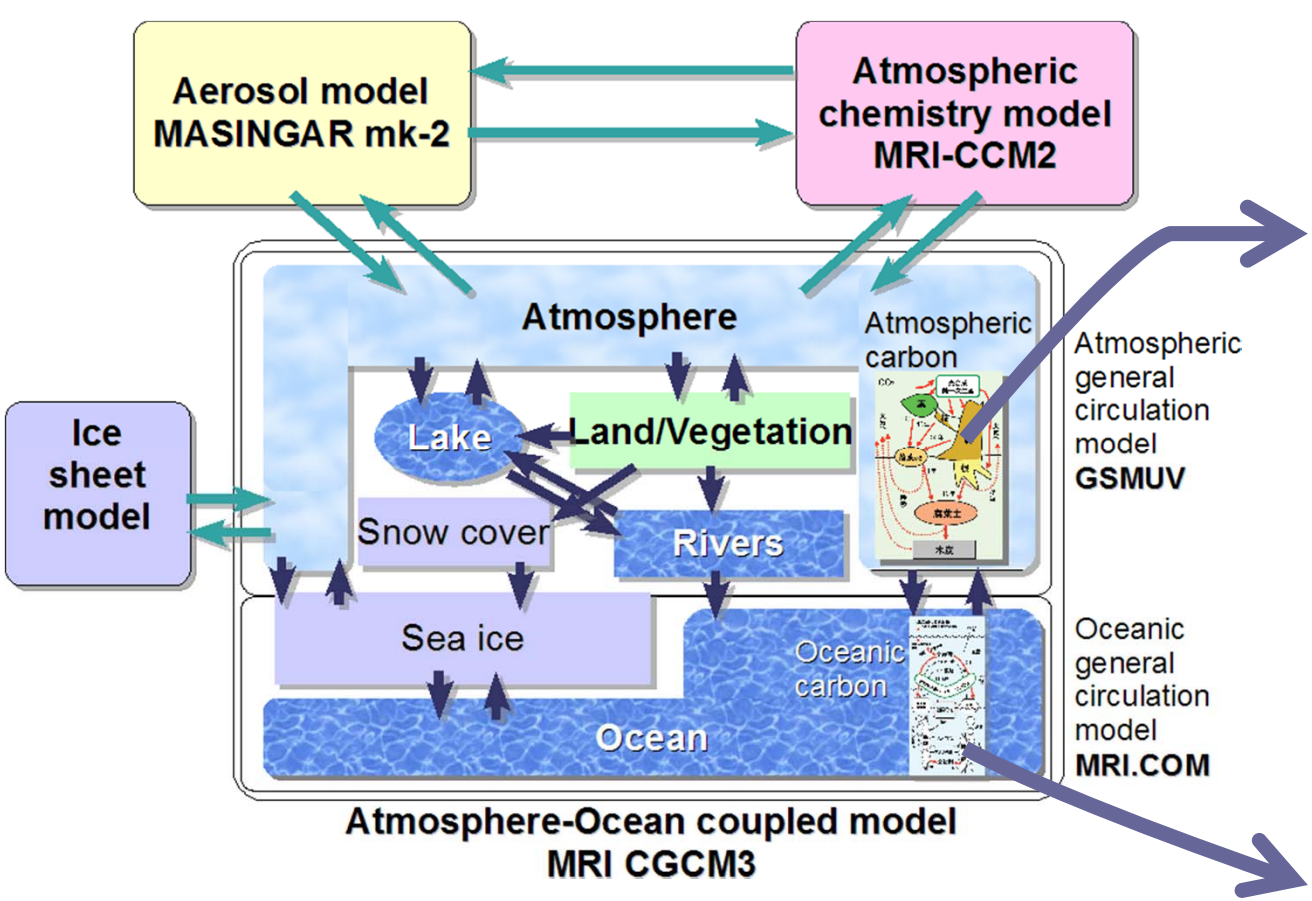
# Aerosol model MASINGAR mk-2

(Model of Aerosol Species in the Global Atmosphere)

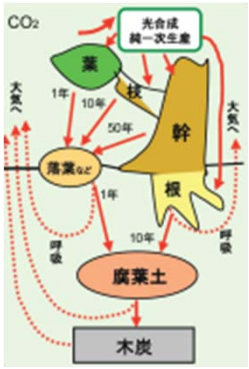
- Five aerosol species are included:
  - Sulfate, black carbon, organic carbon
  - Sea salt, and Mineral dust
    - Particle size distributions are expressed by sectional approach (6-bins from 0.2 to 20 μm)
  - Depending on purposes, volcanic ash, radioactive materials
- The emission flux of mineral dust, sea-salt, and dimethylsulfide are calculated based on the surface properties calculated by the atmospheric model, MRI-AGCM3.

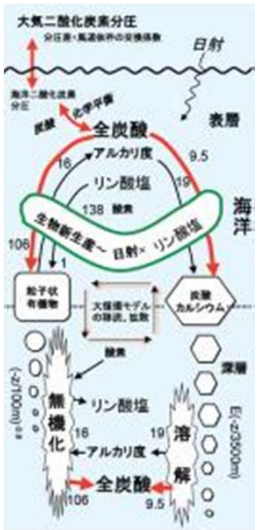
# The MRI Earth System Model

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




Carbon cycle model

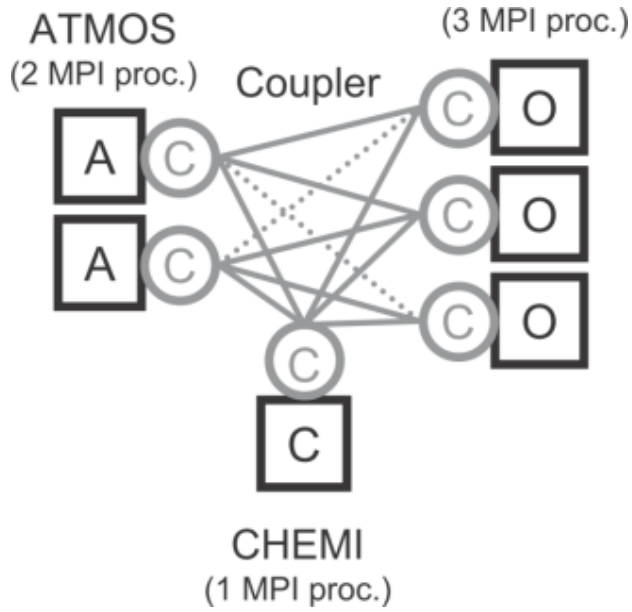



- The model components are connected using a coupler library called SCUP, which couples each model using Message Passing Interface (MPI).

# The Coupler Library, Scup

- Scup (Simple coupler) is a simple and easy-to-use general-purpose coupler for coupling component models.
  - Efficient data exchang 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-dimentional and 3-dimentional coordinate/grid transformation among the models.
  - All written in Fortran 95 and therefore easy to be compiled.
  - Flexible configuration of coupling with namelist file.



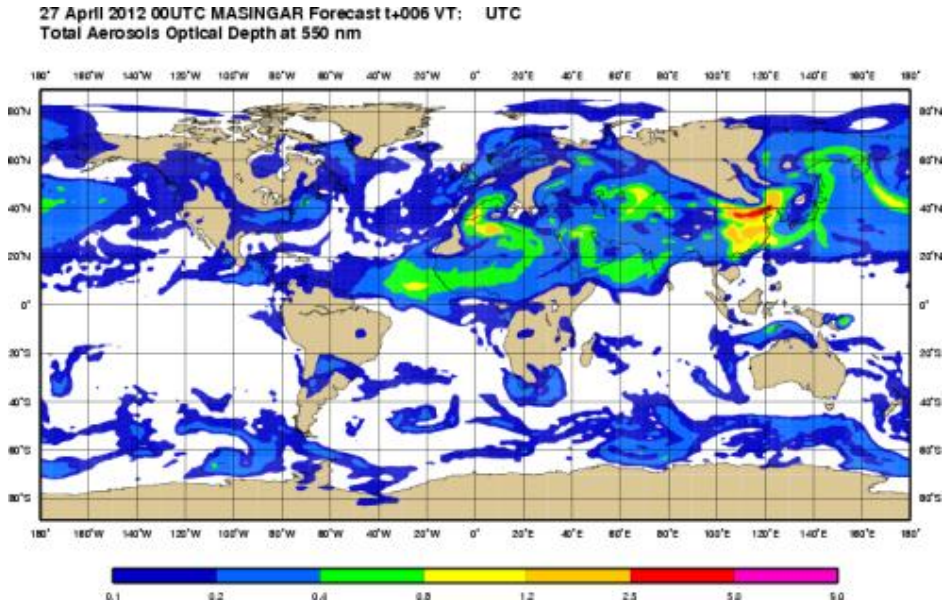

(Yoshimura and Yukimoto, 2008)

# Update of aerosol forecasting model

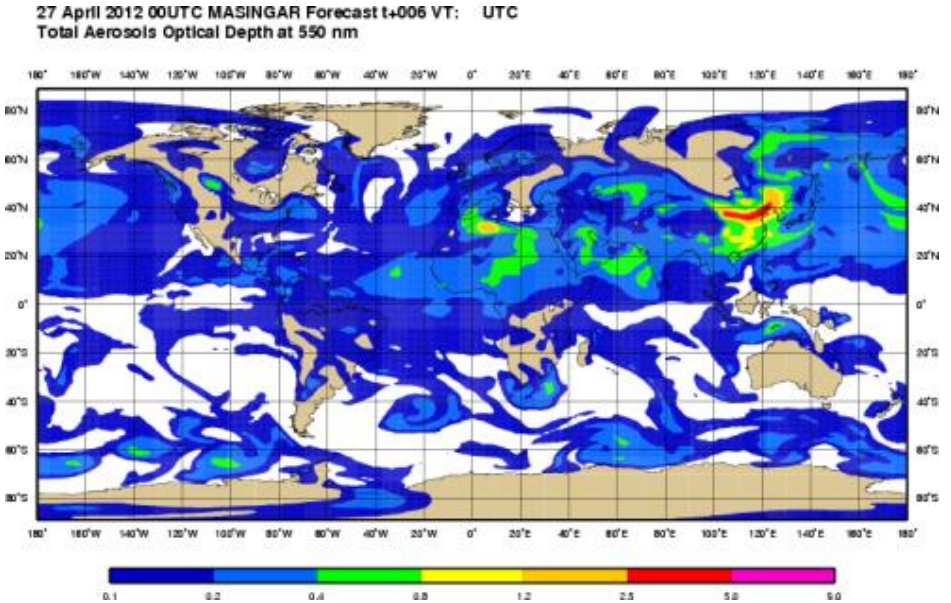
| | Current operational global dust forecast model | Next global aerosol model |
|---|---|---|
| Global aerosol model | MASINGAR (Tanaka et al. 2003) | MASINGAR mk-2 (Tanaka et al., manuscript in preparation) |
| Dust emission | Function of 10m wind speed $F = C\,u_{10}^2(u_{10} - u_t)$ | Function of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

# Quick comparison

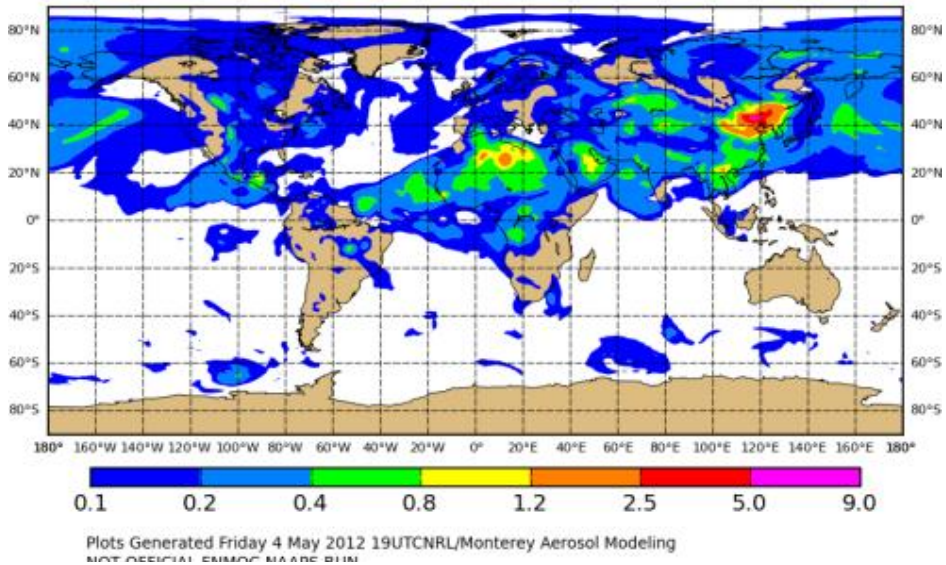
## MASINGAR



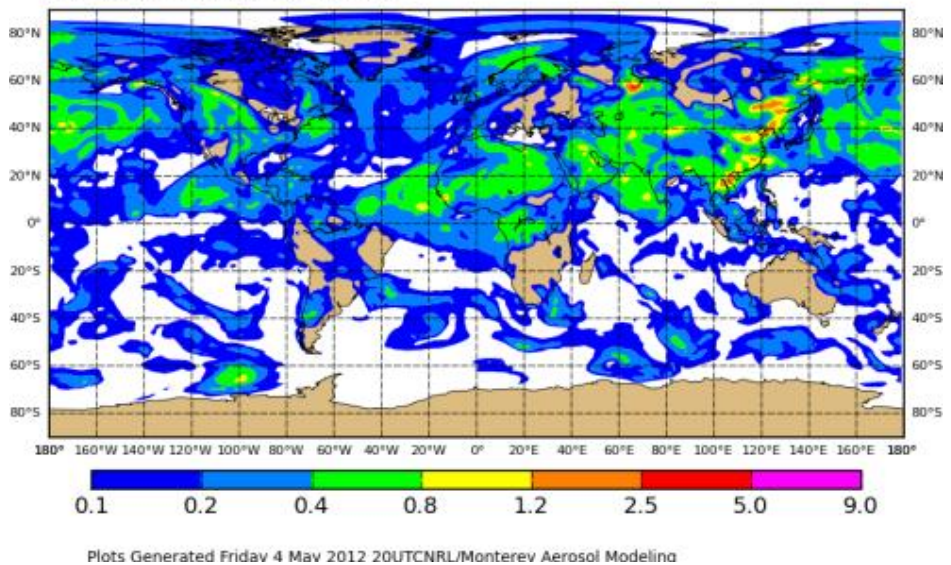

## MASINGAR mk-2

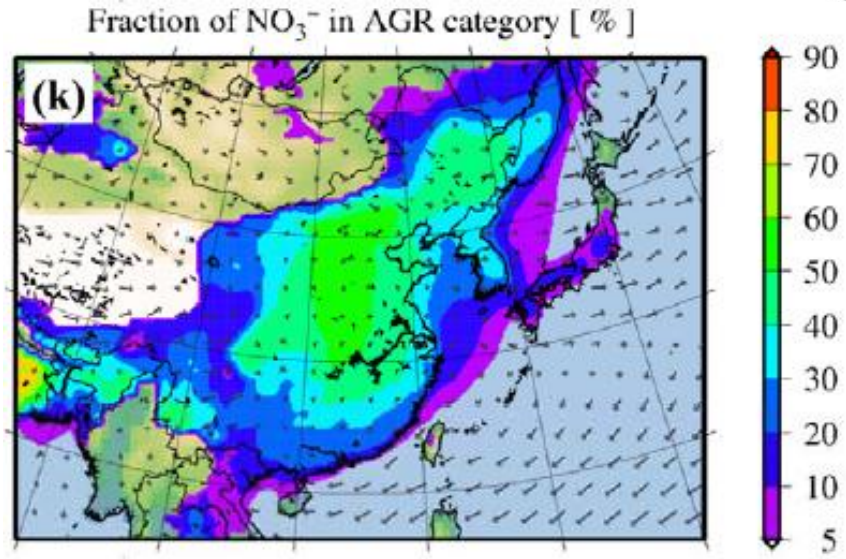



## NAAPS




## MACC






# Development of the regional aerosol/air quality model (NHM-Chem)

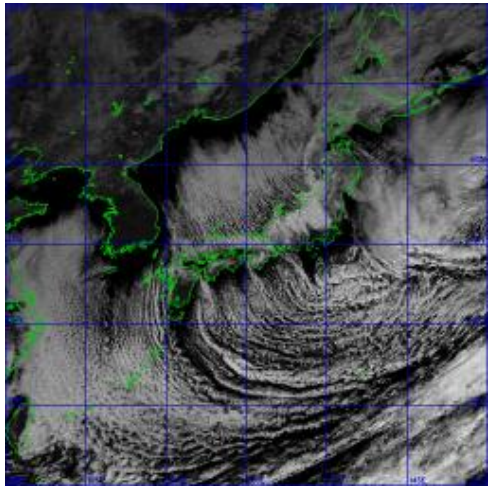
M. Kajino, M. Deushi, T. Maki, T. T. Sekiyama, Y. T. Tanaka, N. Oshima
T. Aoyagi, A. Hashimoto and M. Mikami

# Motivation

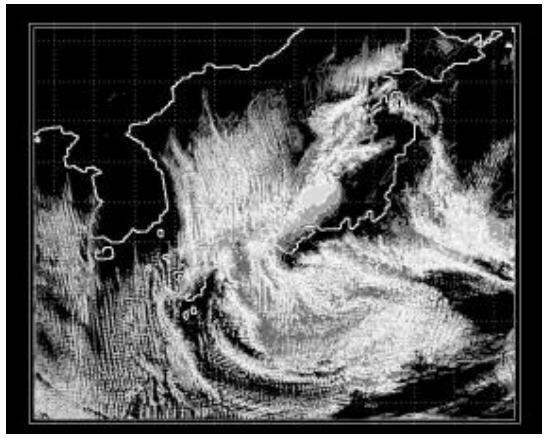
- Operational Forecast:
  For more detailed forecast in finer resolution, regional chemical transport model (CTM) is desirable.
- Research activity:
  It is desirable to include physically and chemically complicated processes, such as aerosol microphysical kinetics and cloud processes, with finer resolution.
- ➔ 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



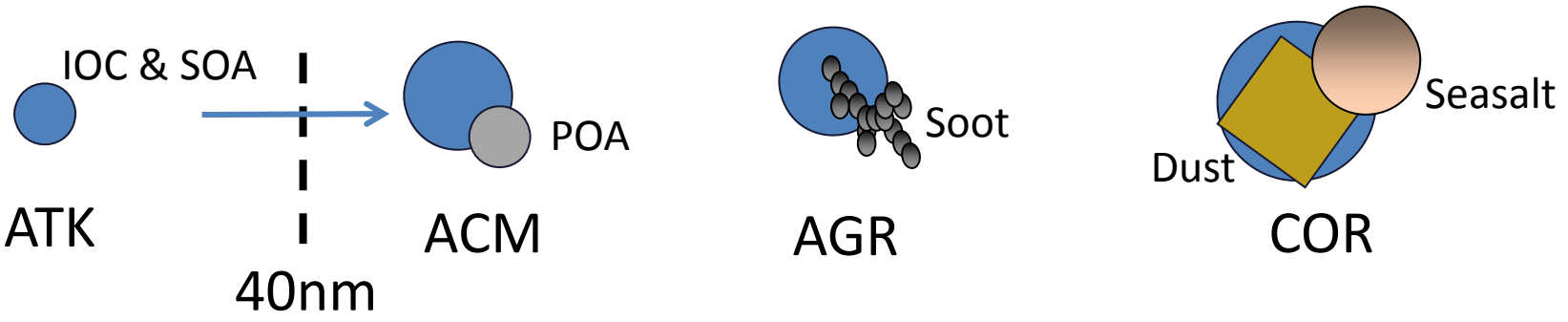
Satellite IR Image



Simulated accumulated water content by NHM (Saito et al. 2001)

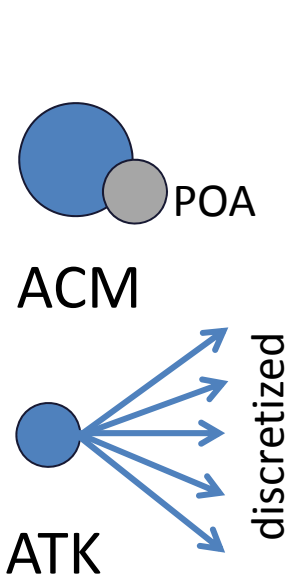
# Category approach: List of aerosol tracers

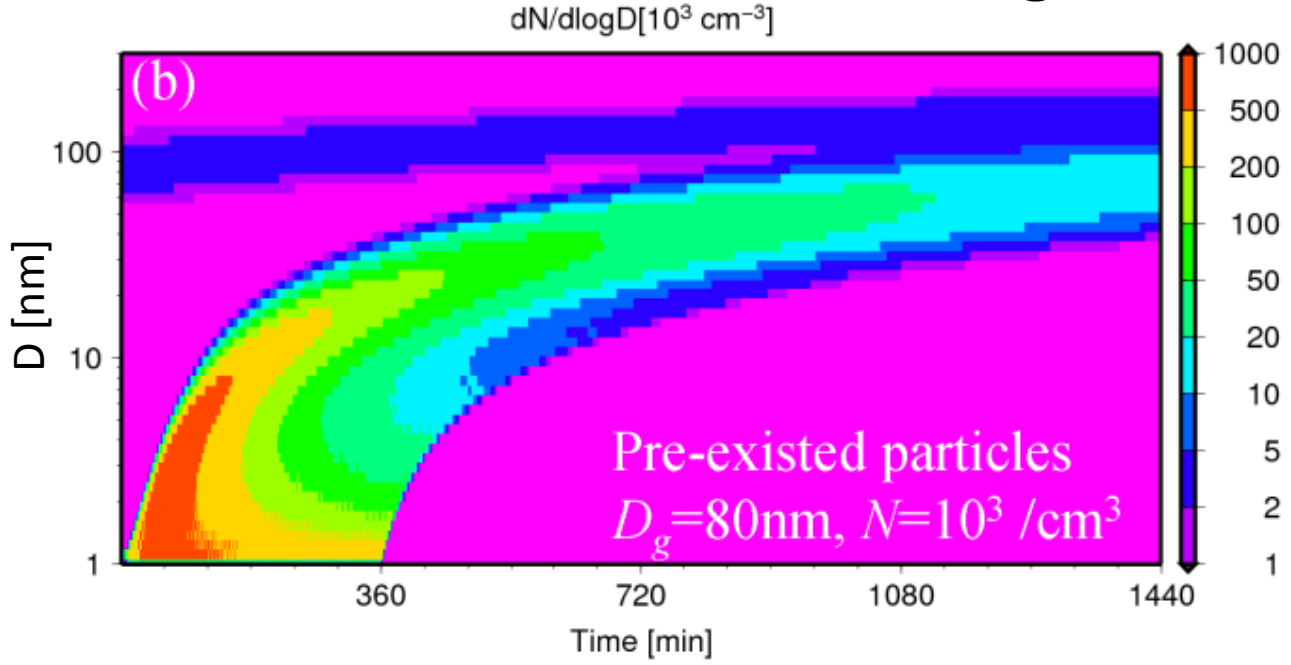
| | Category name | Physical components | | Chemical compositions | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ATK | $M_0$ | $M_2$ | - | - | OA | - | - | $SO_4^{2-}$ | $NH_4^+$ | $NO_3^-$ | $Cl^-$ | $H_2O$ |
| 2 | ACM | $M_0$ | $M_2$ | UID | - | OA | - | - | $SO_4^{2-}$ | $NH_4^+$ | $NO_3^-$ | $Cl^-$ | $H_2O$ |
| 3 | AGR | $M_0$ | $M_2$ | UID | BC | OA | - | - | $SO_4^{2-}$ | $NH_4^+$ | $NO_3^-$ | $Cl^-$ | $H_2O$ |
| 4 | COR | $M_0$ | $M_2$ | UID | BC | OA | DU | SS | $SO_4^{2-}$ | $NH_4^+$ | $NO_3^-$ | $Cl^-$ | $H_2O$ |
| | | $M_0^{AGR}$ | | | | | | | | | | | |

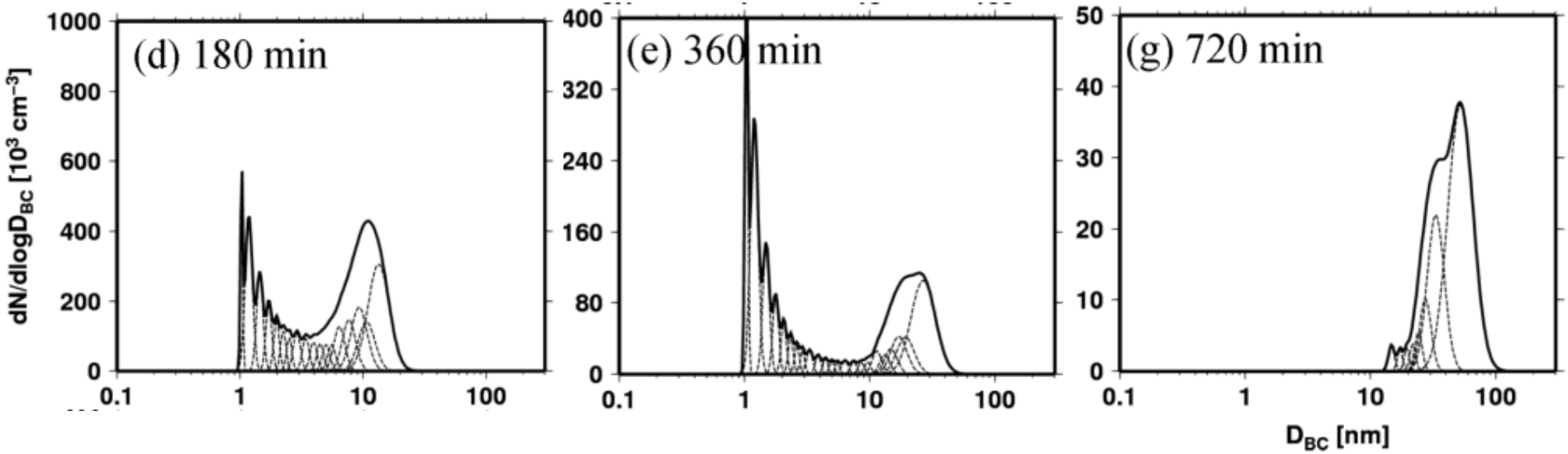



Gas chem. (SAPRC99), NPF (Kuang), SOA (CMAQ-AE5), Aqueous chem. (RADM)
4-7 categories are used for the 3-D simulation (SS, DU, POL)
MADMS: 3 moment bulk aerosol dynamics model.

# MBHM: a box model simulation using 64bins

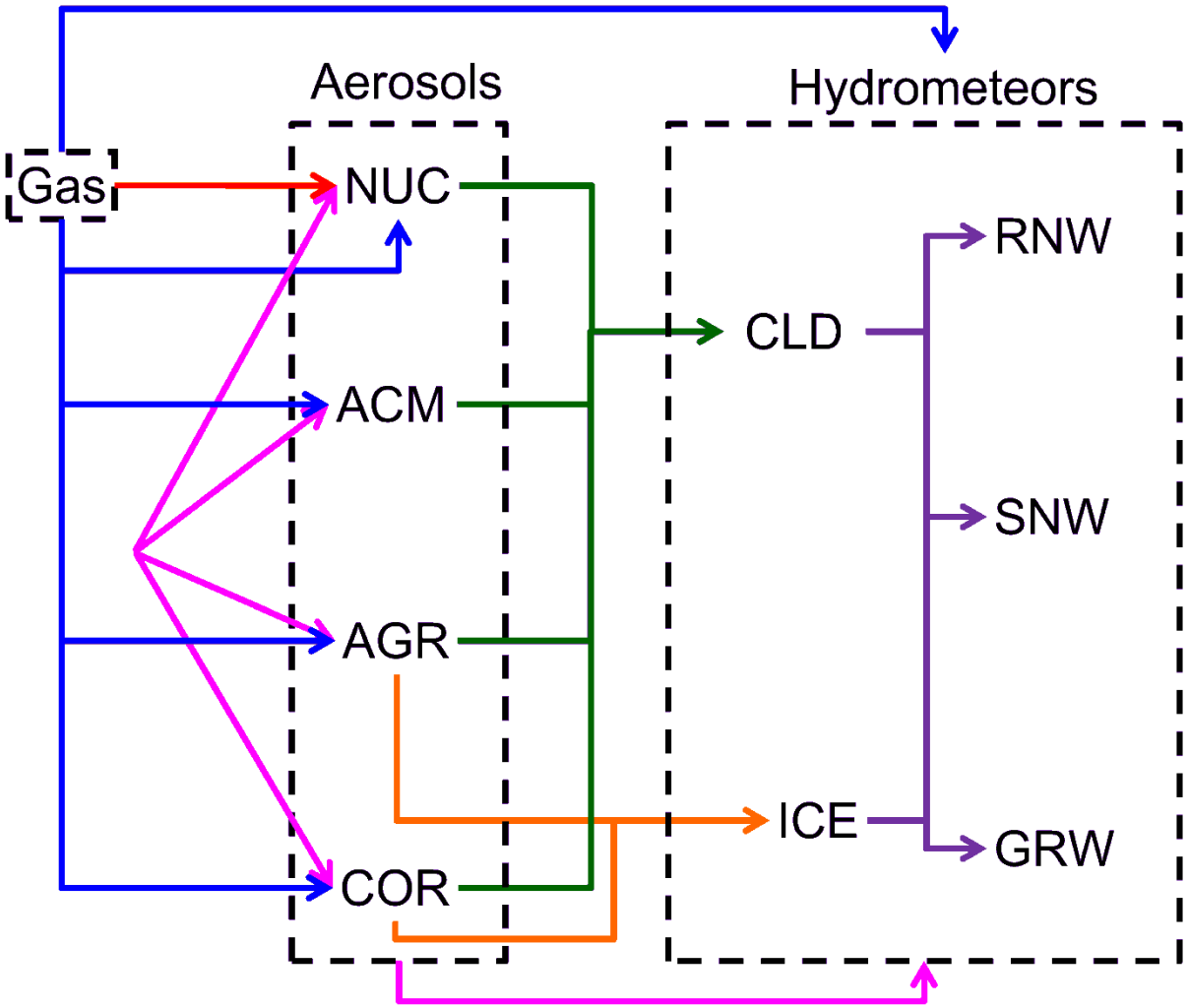



Banana curve cannot be resolved using a single modal approach

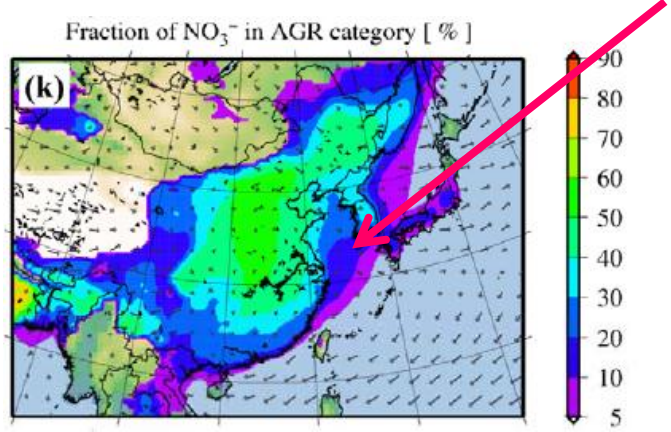
# A category approach for aerosol and cloud microphysics




- Nucleation
  Kuang et al. (2008)
- Condensation
  Kajino (2011)
- Coagulation
  Kajino (2011)
- CCN activation
  Abdul-Razzak and Ghan (2000)
- IN activation
  Lohmann and Diehl (2010)
- Cloud microphysics
  Lin et al. (1983)

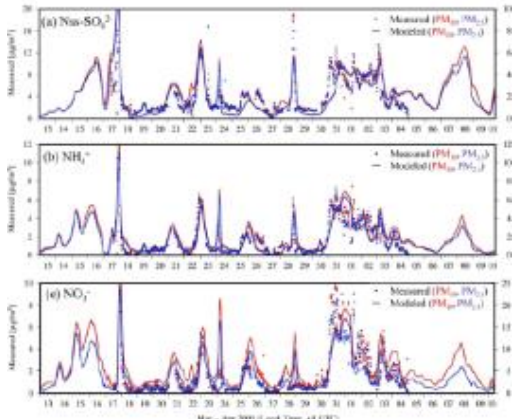
- Aerosols category based on formation mechanisms
- Size distribution of each category characterized as uni-modal LNSD.

# Modeling aerosol chemistry, size and mixing type



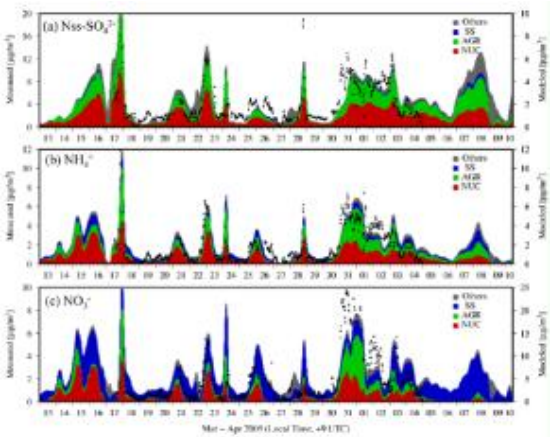

Nitrate mixed with soot [%]
(affect optical property)

PM2.5/PM10 ratio at Jeju

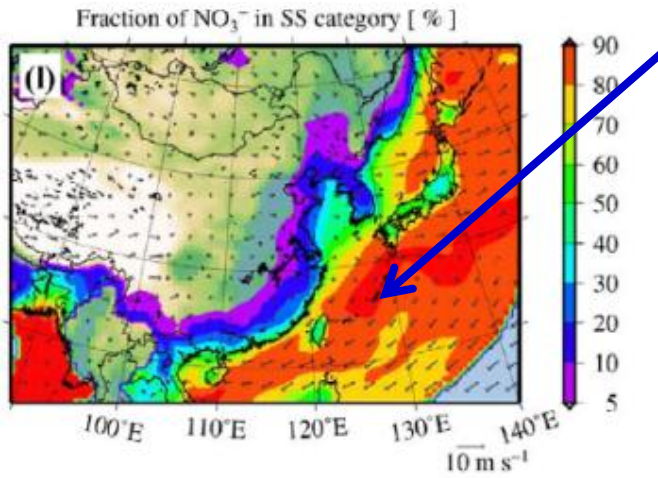


The ratios are 0.9, 0.67, and 0.5 for SO4, NO3, and Na both in observation and simulation.

Mixing type at Jeju

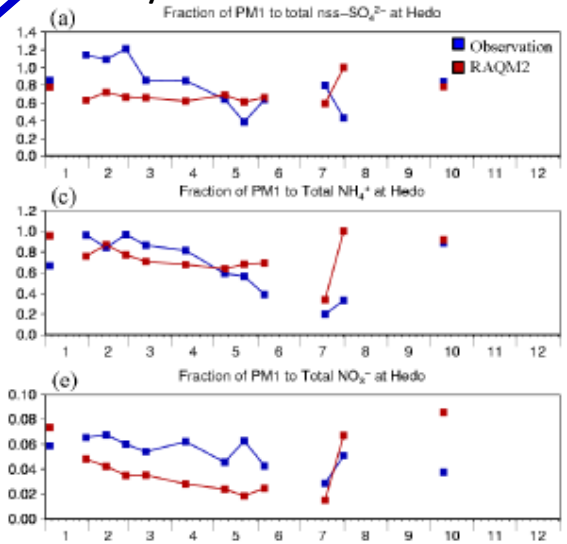


60% of nitrate with sea salt



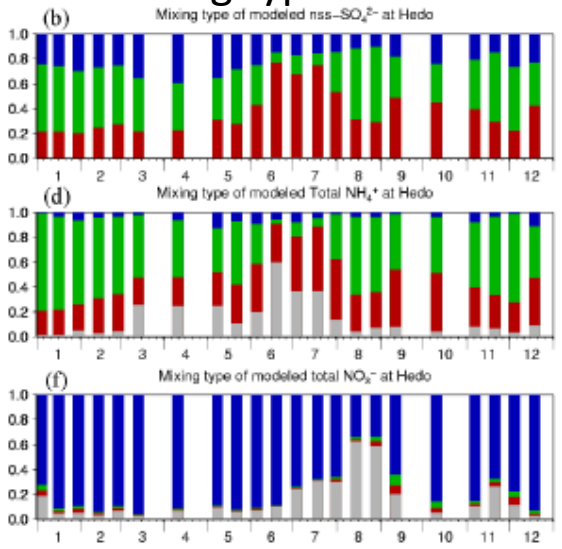

Nitrate mixed with sea salt [%]
(not affect very much)

PM1/TSP ratio at Hedo

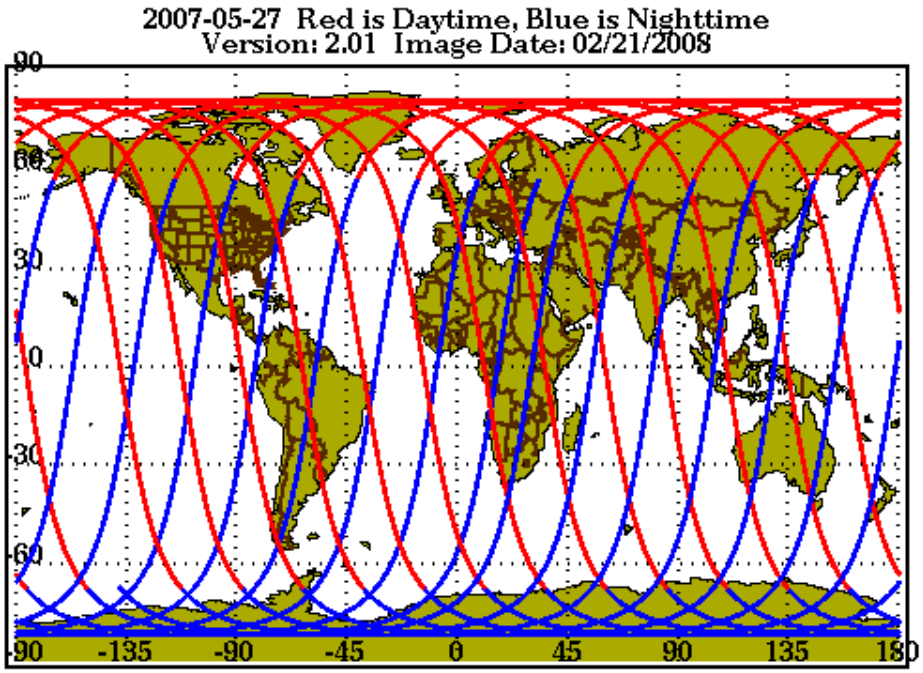



SO4は~1，NO3は<0.1

Mixing type at Hedo



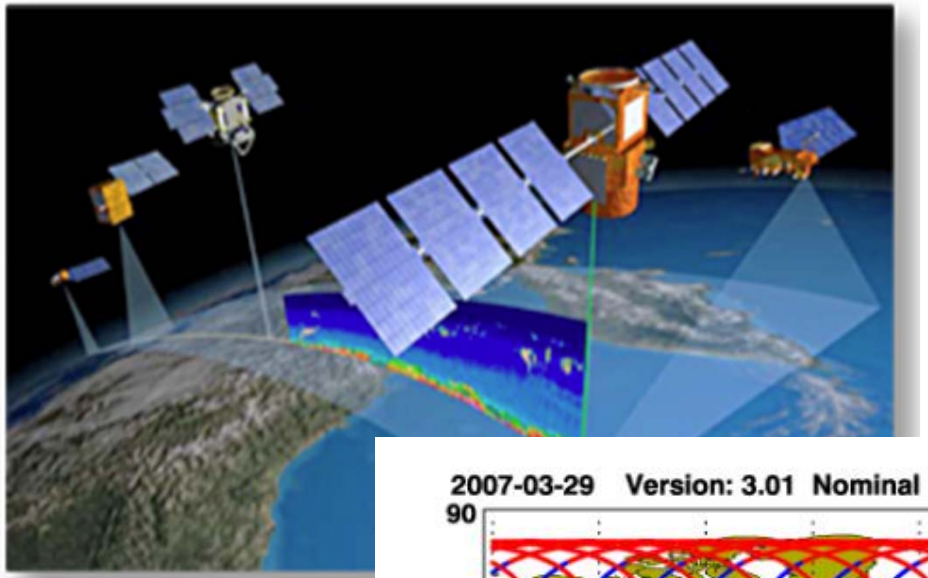

>90% of nitrate with sea salt



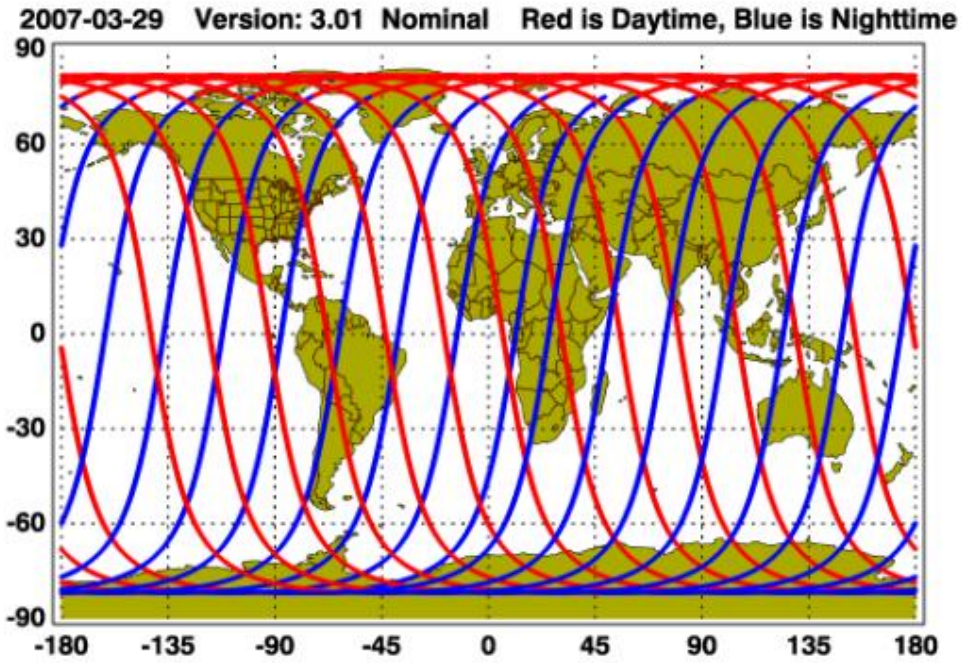

# Data assimilation: OSSE and validations with MET/MODE

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.

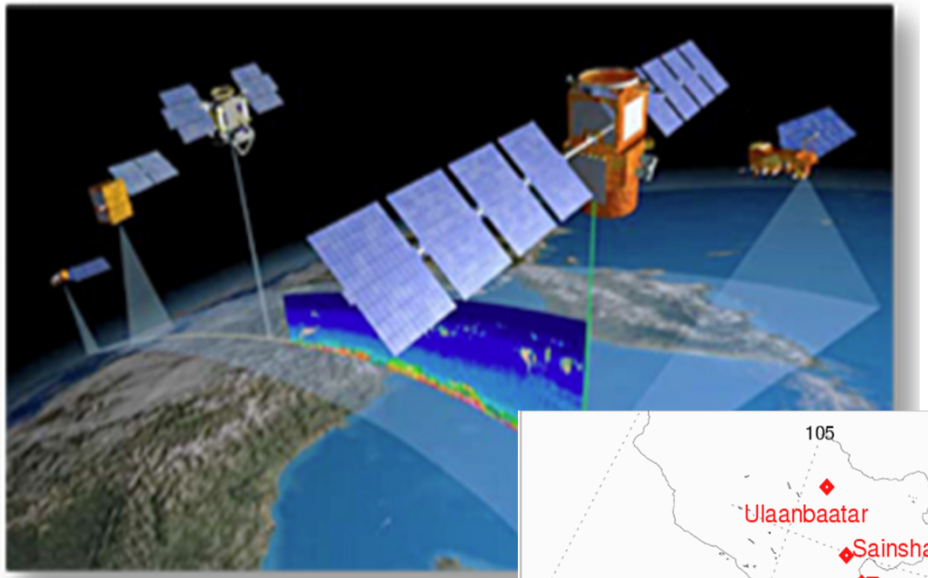



Lidar view angle: almost zero…

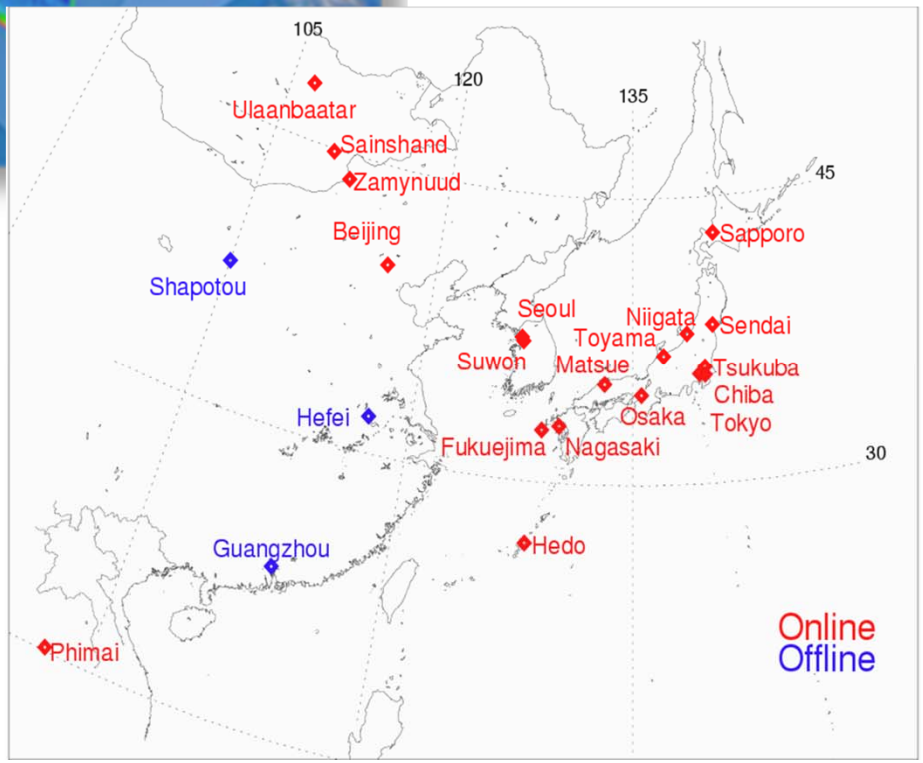
Data density: very sparse horizontally…

But it has vertical profiles.

# EnKF for aerosol analysis

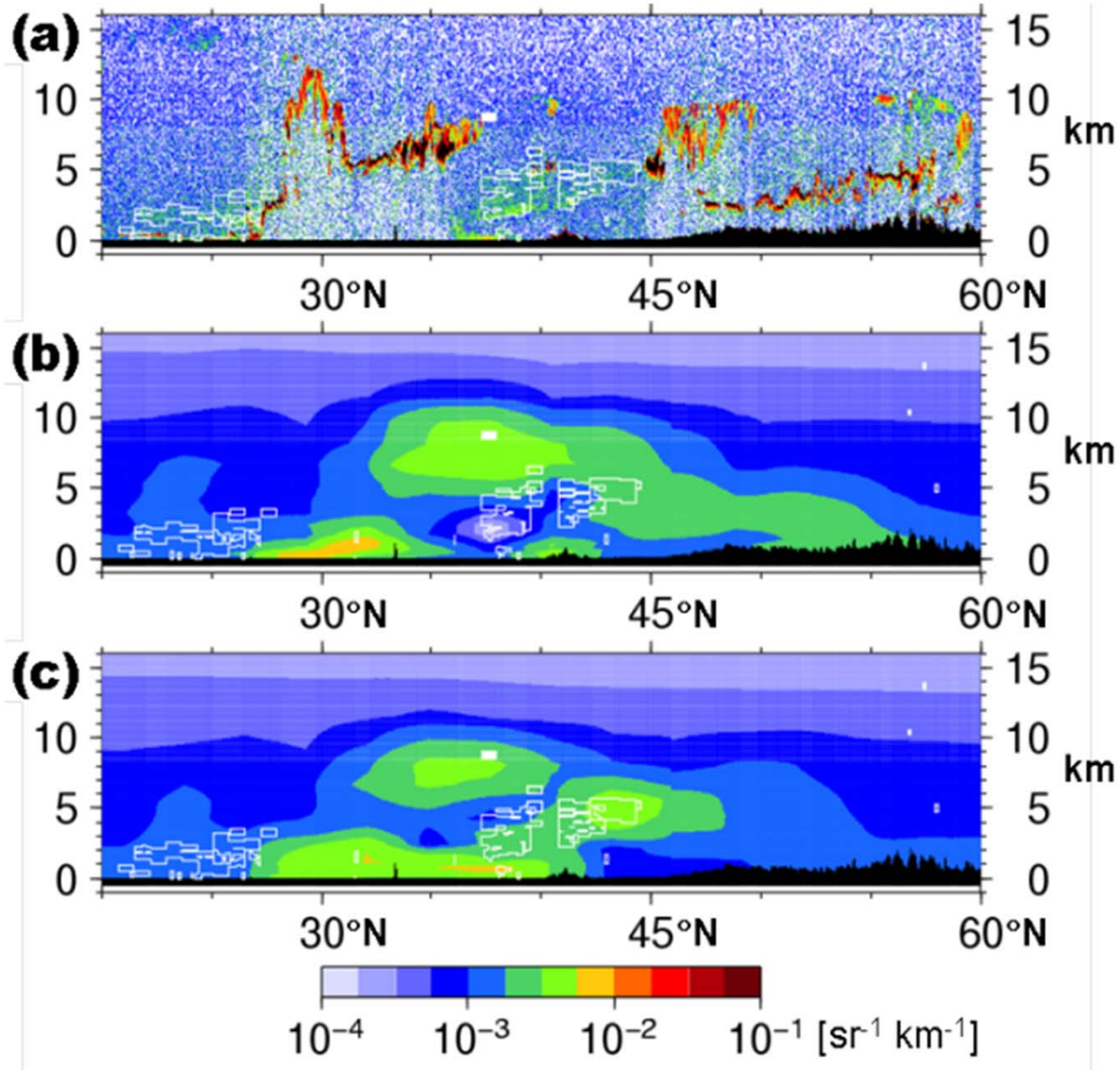


**Satellite Lidar observation (CALIPSO/CALIOP):**
NASA launched the polar-orbit satellite in 2006.




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

# EnKF for aerosol analysis




Sekiyama et al., ACP (2010)

**Observation Variables**: attenuated backscattering coeff. at 532 nm;

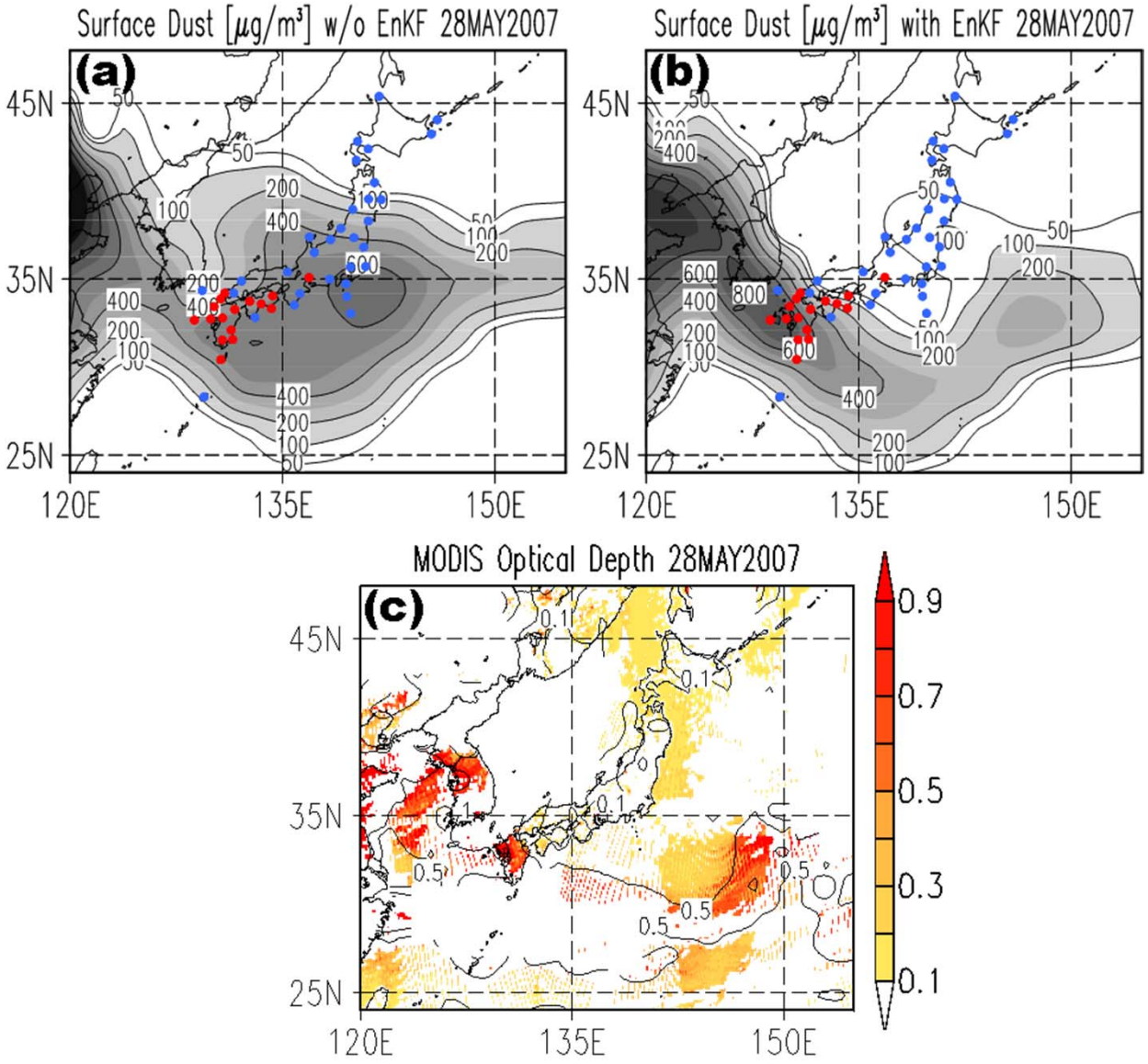
a) CALIPSO/CALIOP;

b) model **without** data assimilation;

c) model **with** data assimilation.

White squares: aerosol plumes.

# 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.*

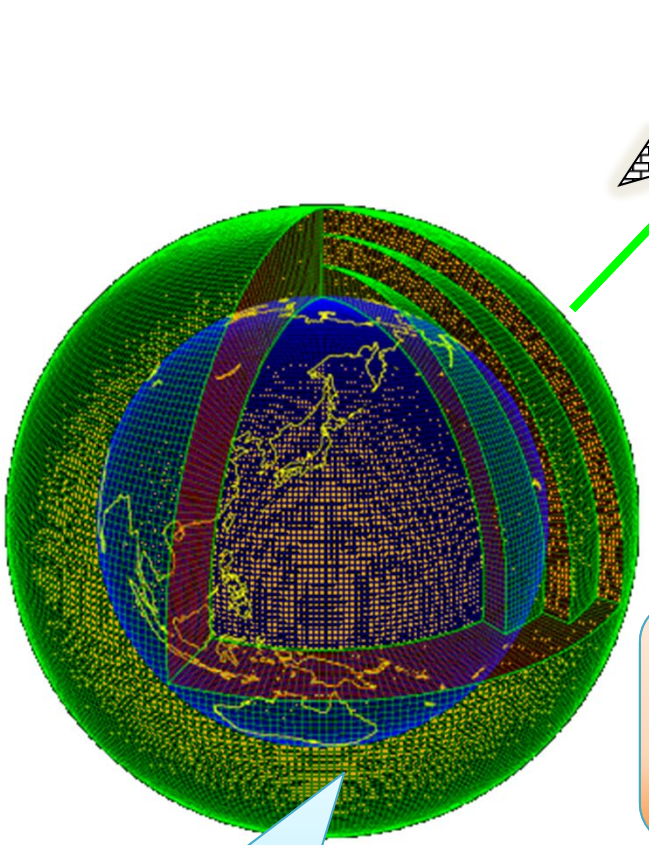
Sekiyama et al., ACP (2010)

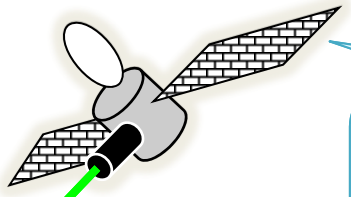
# What is an OSSE?

- 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

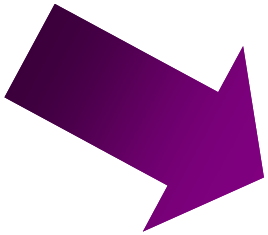
(In the real world, we cannot really know the true values or observational errors.)

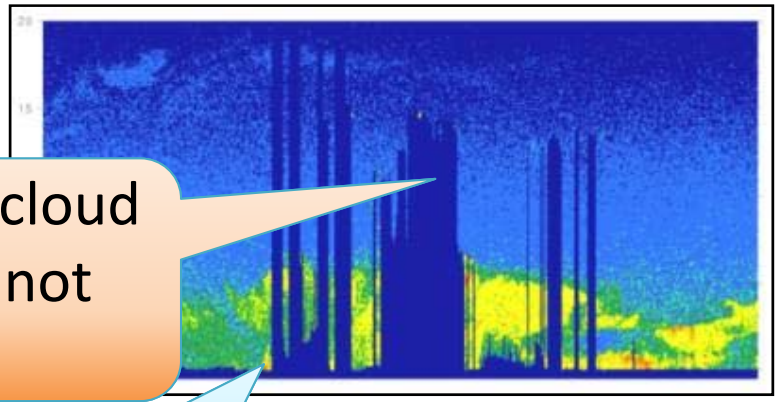
# What is the virtual world of OSSE?





If CALIPSO is working in this virtual space…





Producing cloud noises is not easy!

Virtual Earth produced by the numerical model

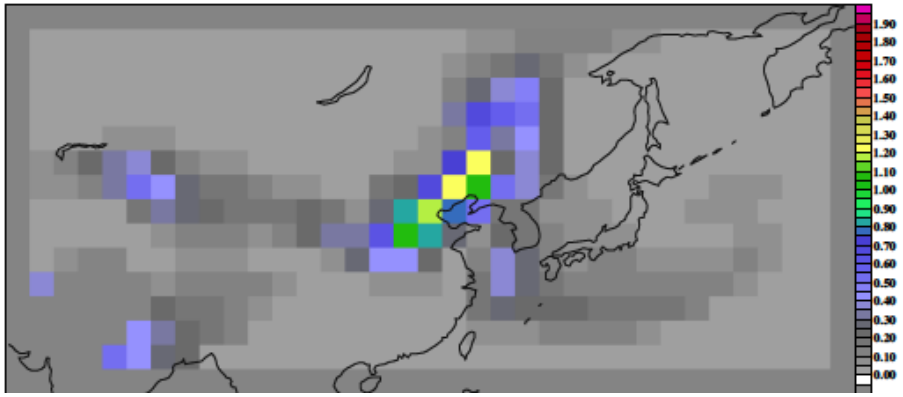
The atmosphere should be observed like this.

# 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 $SO_2$
    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).

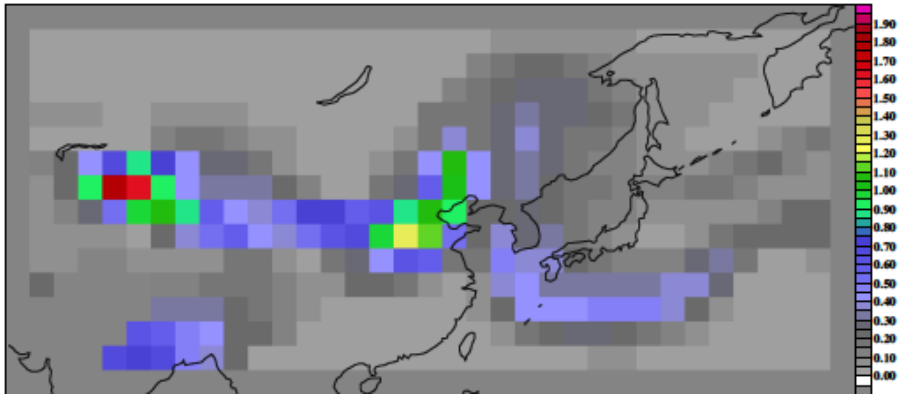
# Assimilate to the virtual observation

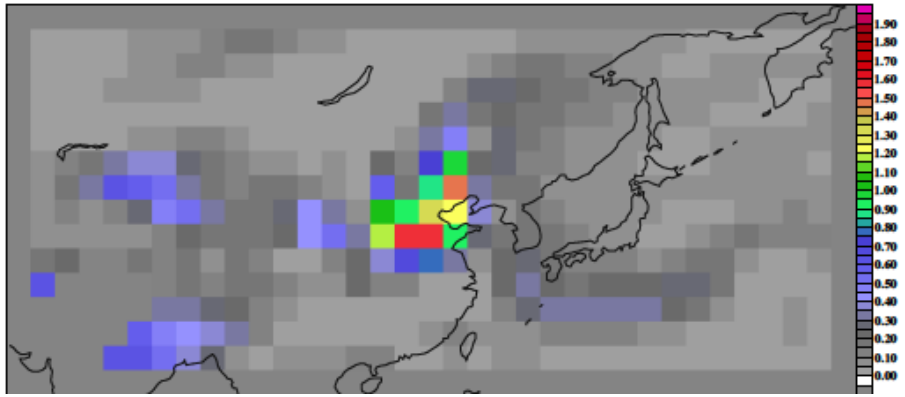
True value (from which virtual observations are made)




Free-run with different boundary condition

Data assimilated distribution using EnKF

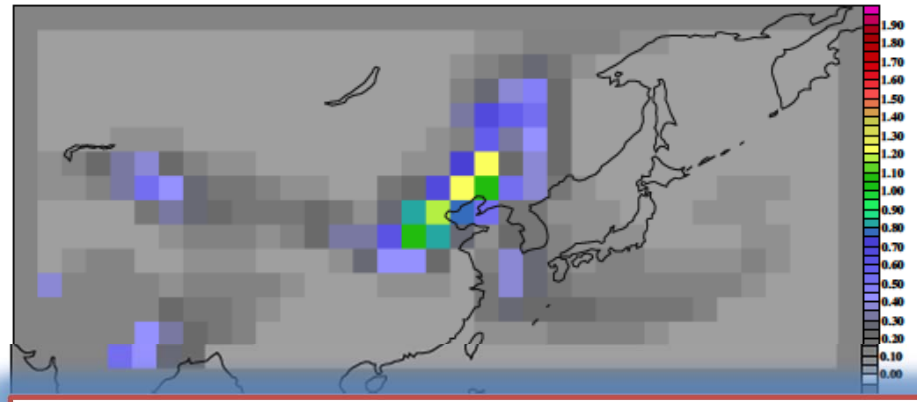



Optical depth of mineral dust (31 May 2007)

# Limitation of the classical evaluation index

True value (from which virtual observations are made)



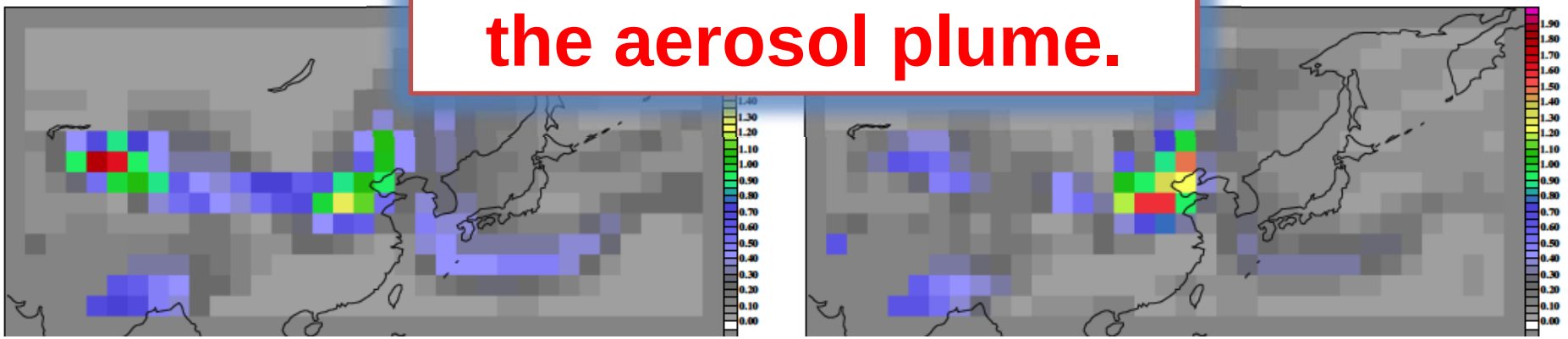
RMSE = 0.135
Abs Corr = 0.795

RMSE = 0.137
Abs Corr = 0.788

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

Free-run with different

tribution using EnKF



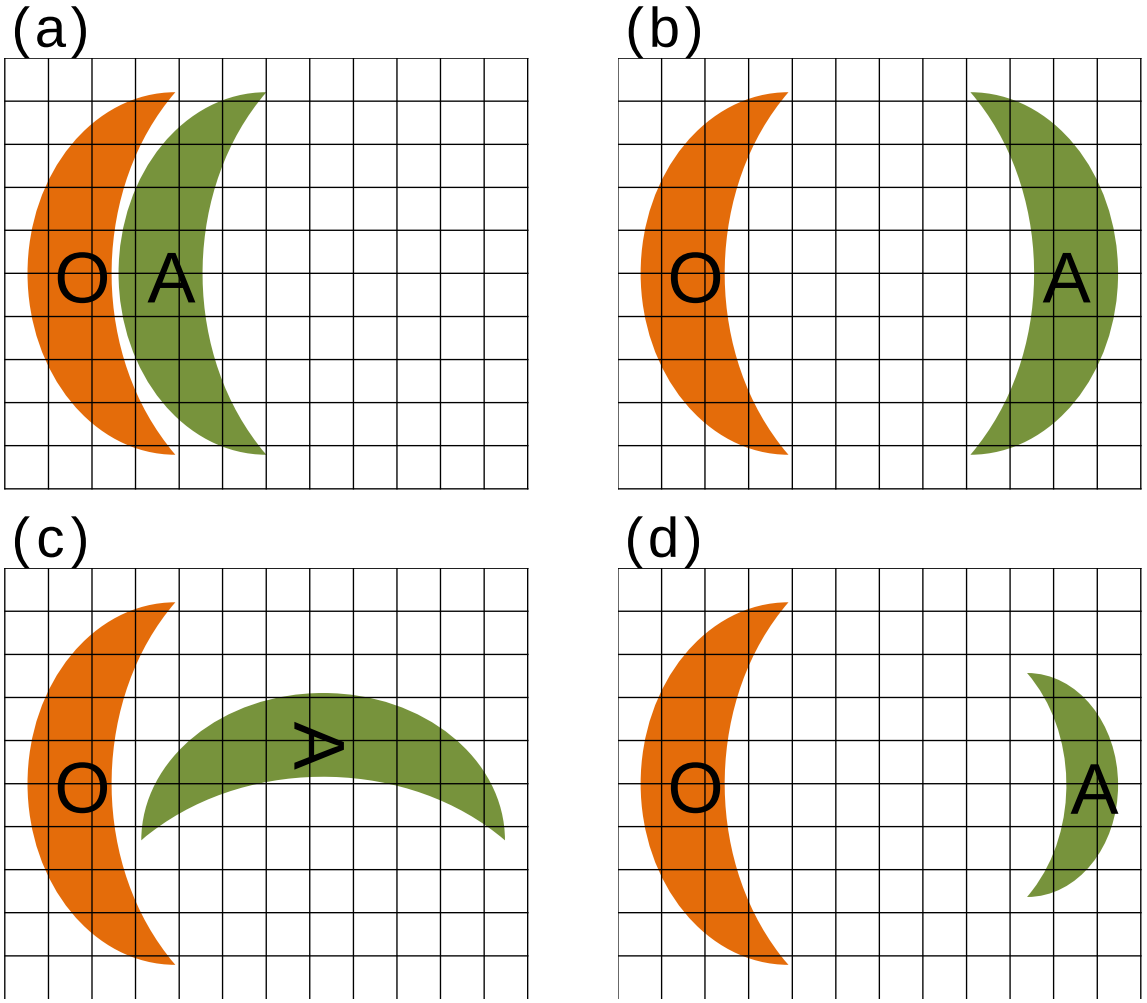
Optical depth of mineral dust (31 May 2007)

# Application of MODE/MET to the evaluation of the data assimilation

# Object-based evaluation (MODE)

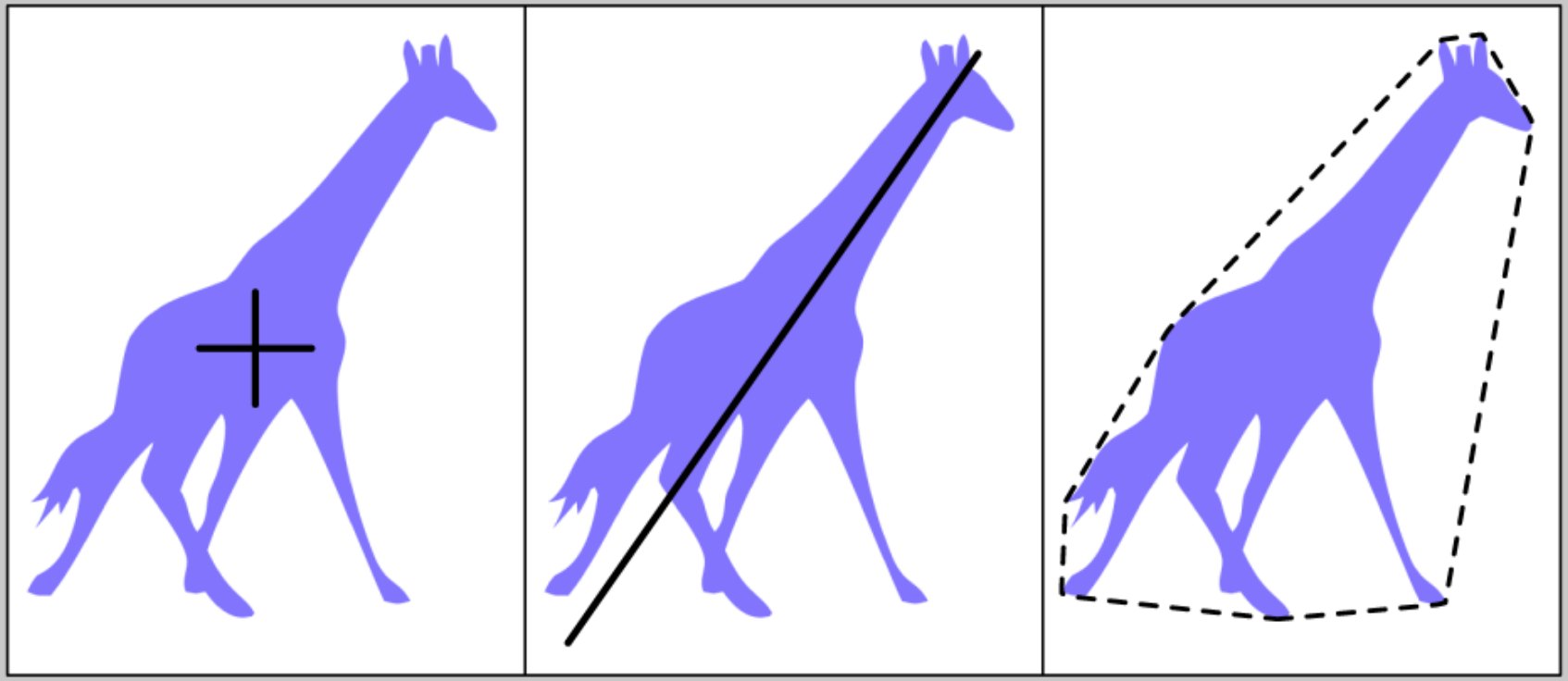
- We used the Method for Object-Based Diagnostic Evaluation (MODE) in Meteorological Evaluation Tool (MET).
  - Recognize the similar distribution with smoothing and pattern matching
  - Compare the attribute of each clusters
  - Quantify the similarities of the clusters
- Source code of MODE is available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

# Background and Motivation



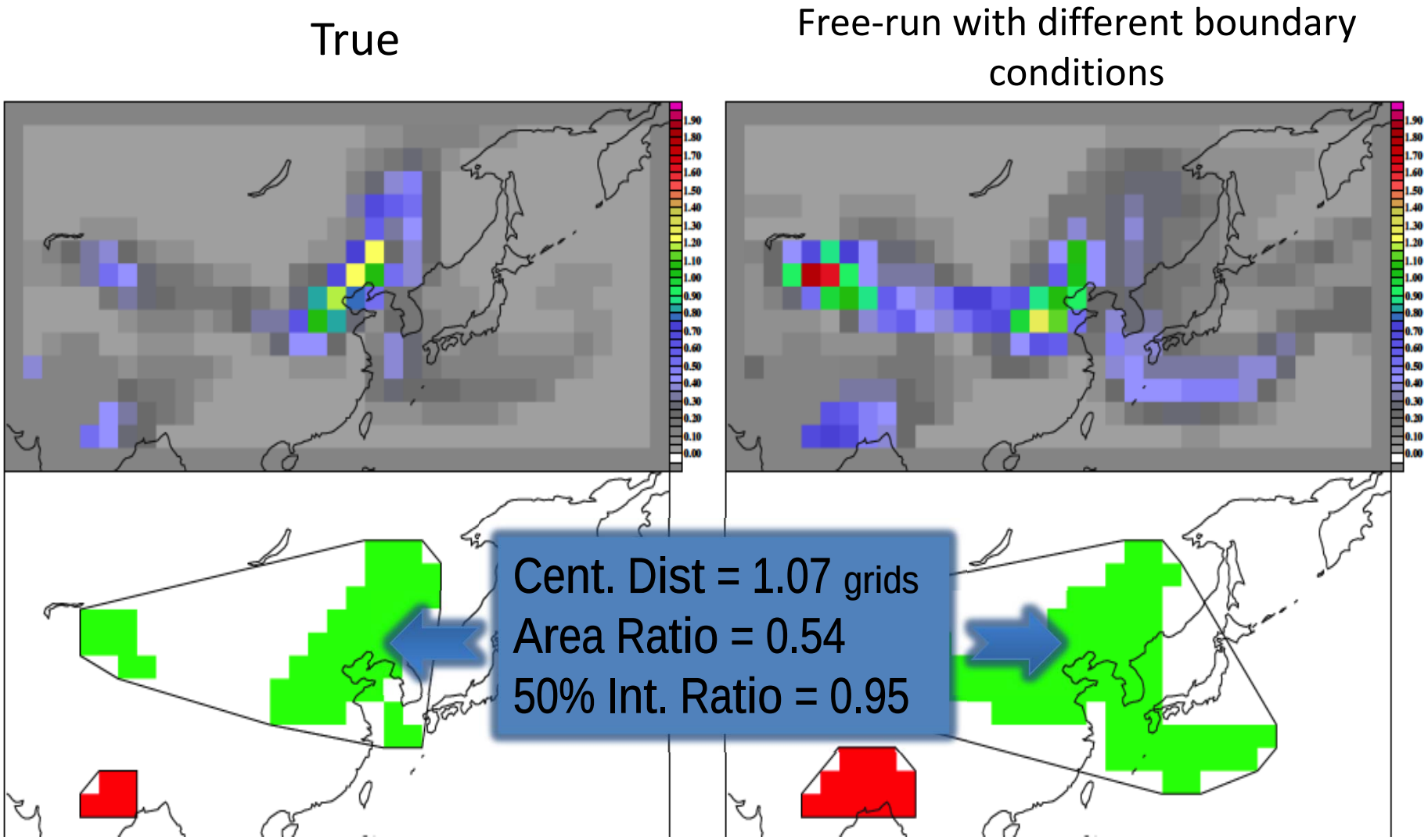

- Which forecast is better?

# Example Single Attributes



Centroid Axis Convex Hull

# MODE analysis of dust: Before data assimilation

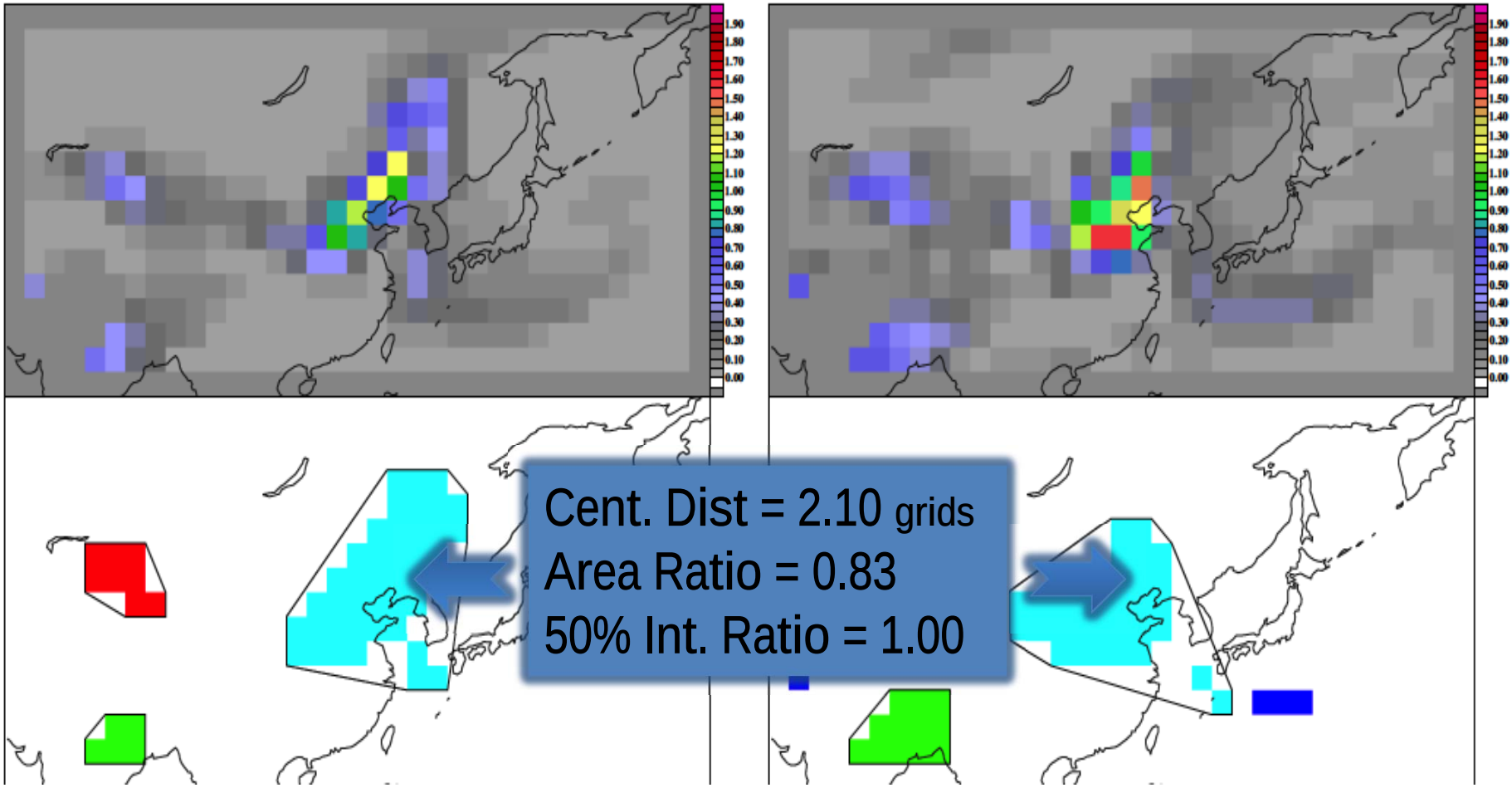



Optical depth of mineral dust (31 May 2007)

# MODE analysis of dust: After data assimilation

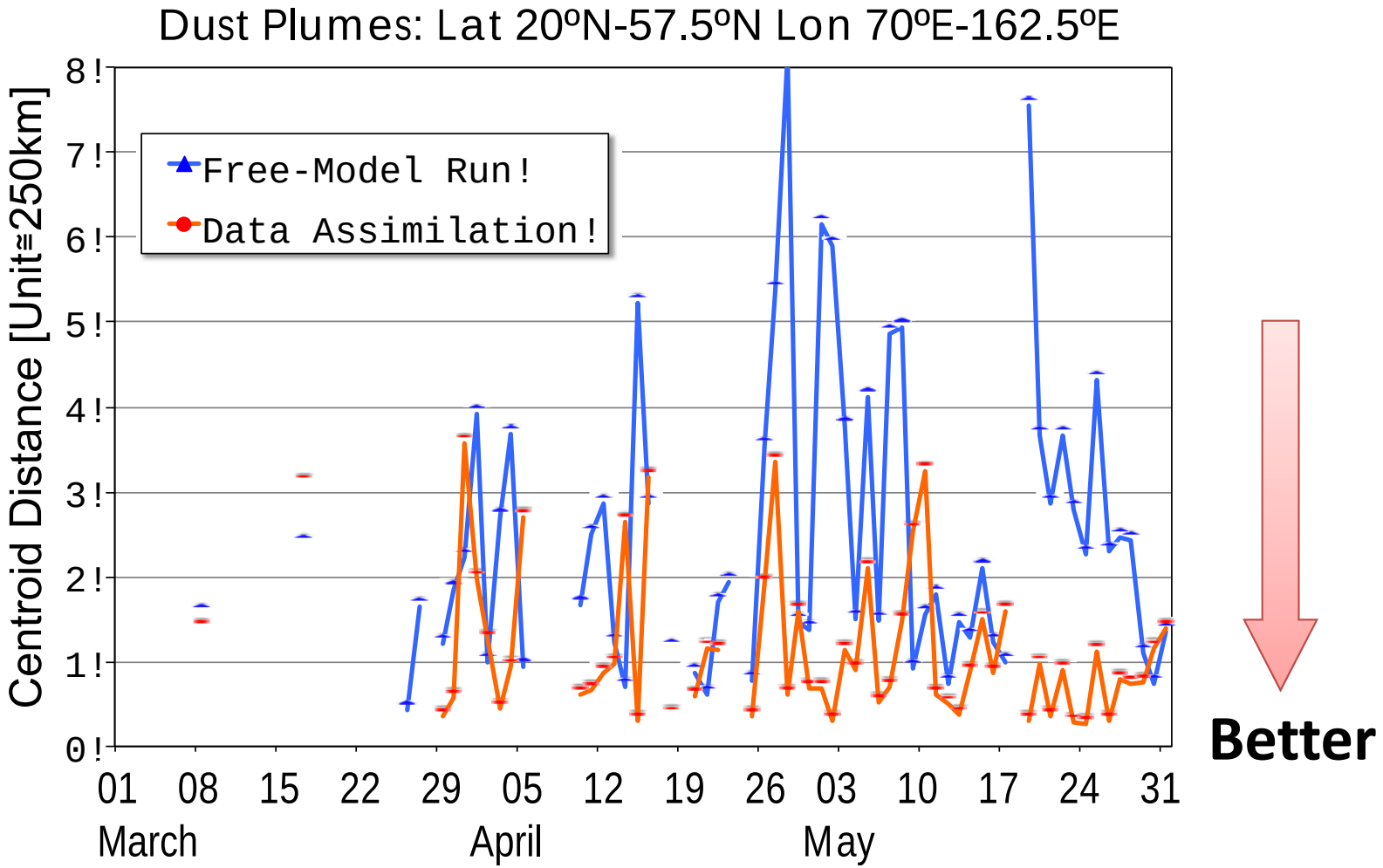
True

Data assimilated result with EnKF



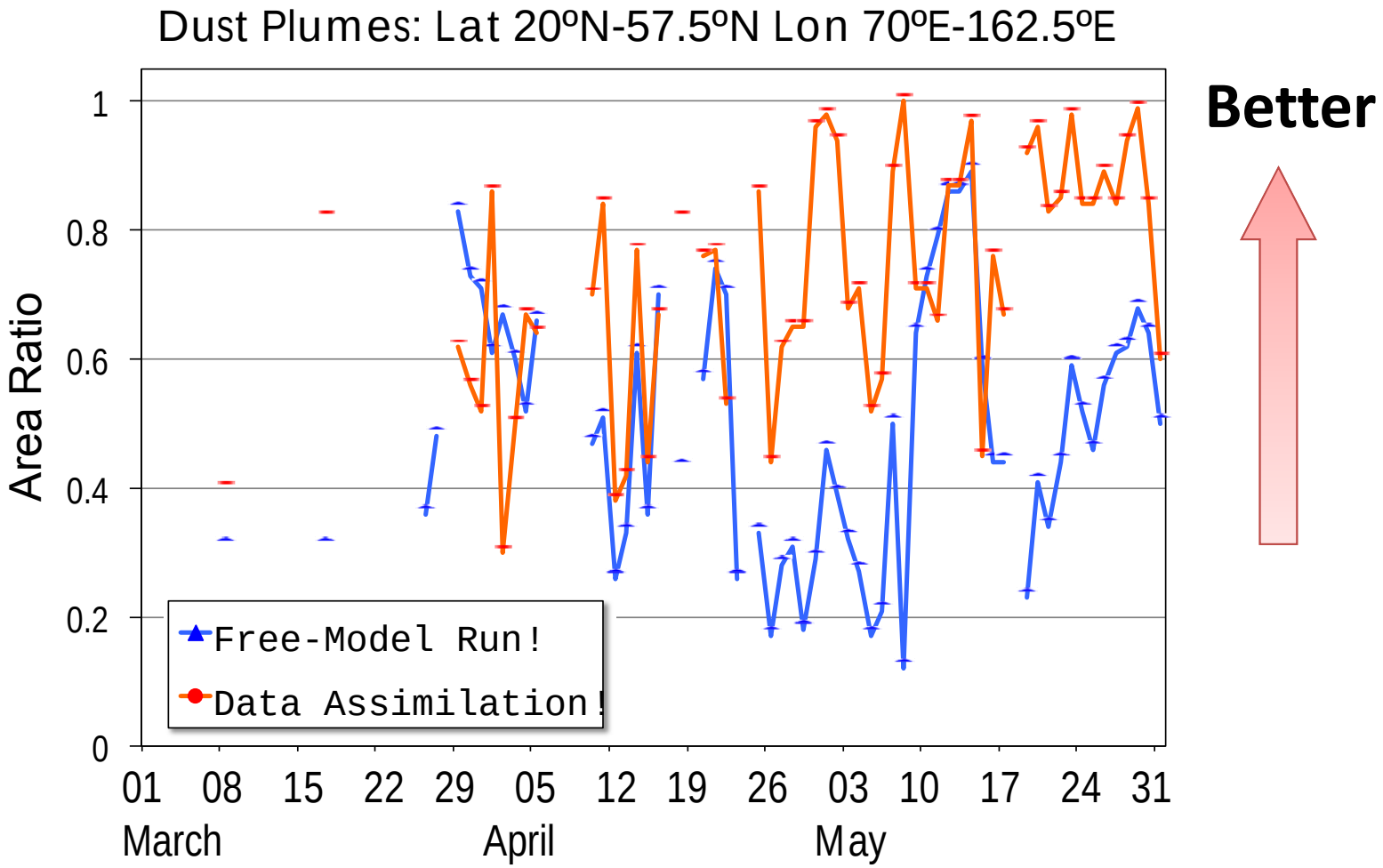

Optical depth of mineral dust (31 May 2007)

# Evaluation using MODE: Dust



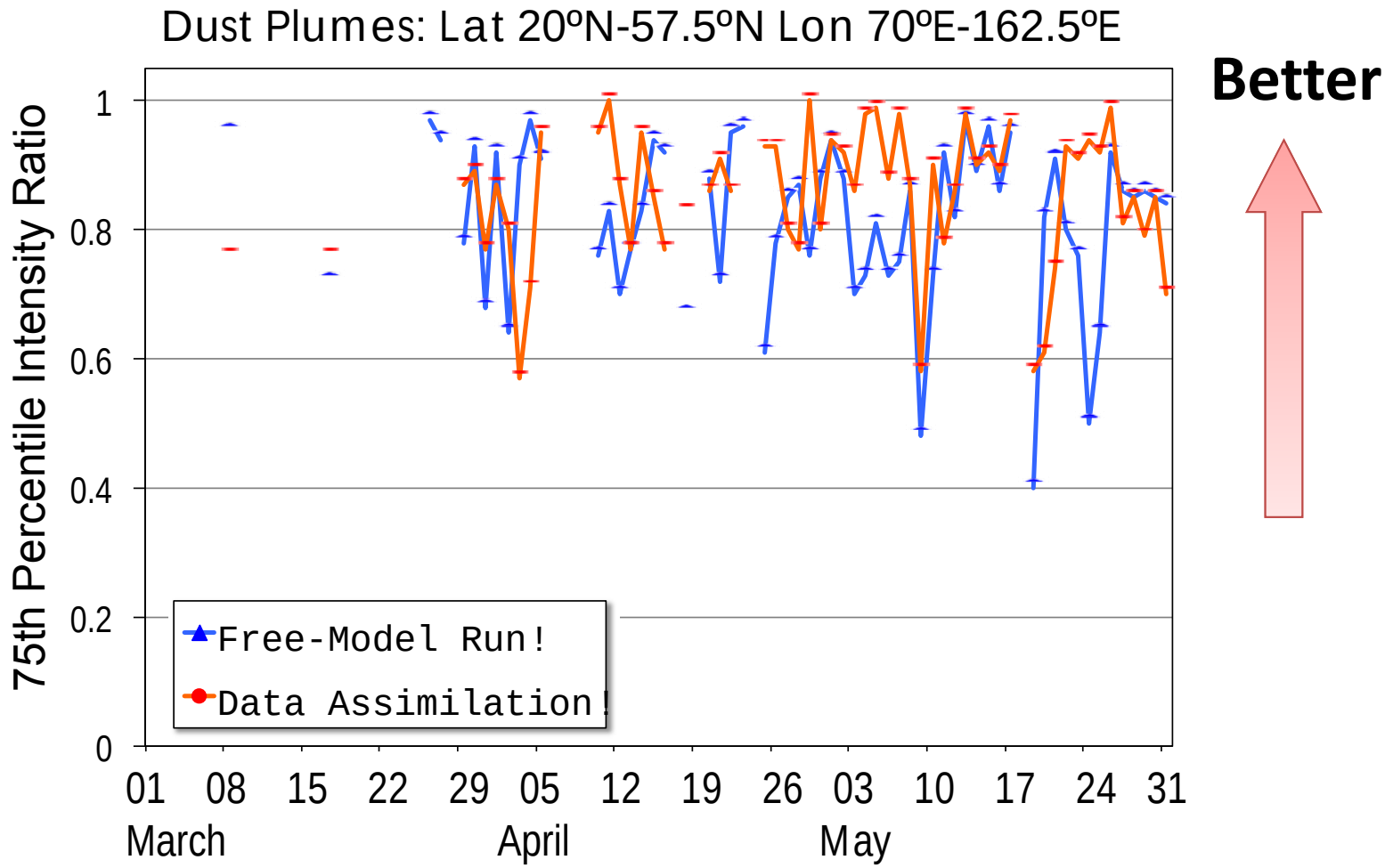

- Averaged centroid distance of dust aerosol AOD in East Asia

# Evaluation using MODE: Dust



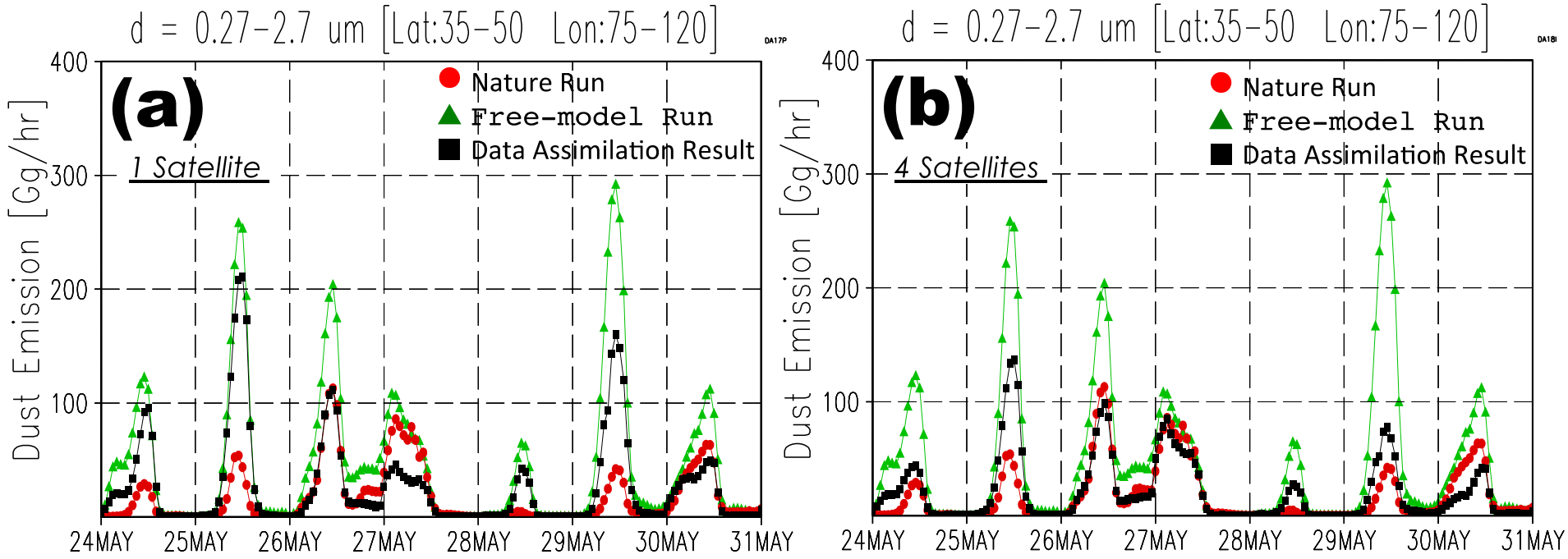

- Averaged area radio of dust aerosol AOD in East Asia

# Evaluation using MODE: Dust




- Averaged intensity ratio of dust aerosol AOD in East Asia

# Sensitivity study of the frequency of CALIPSO observation




Total dust emission : 1 satellite

Total dust emission : 4 satellite

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

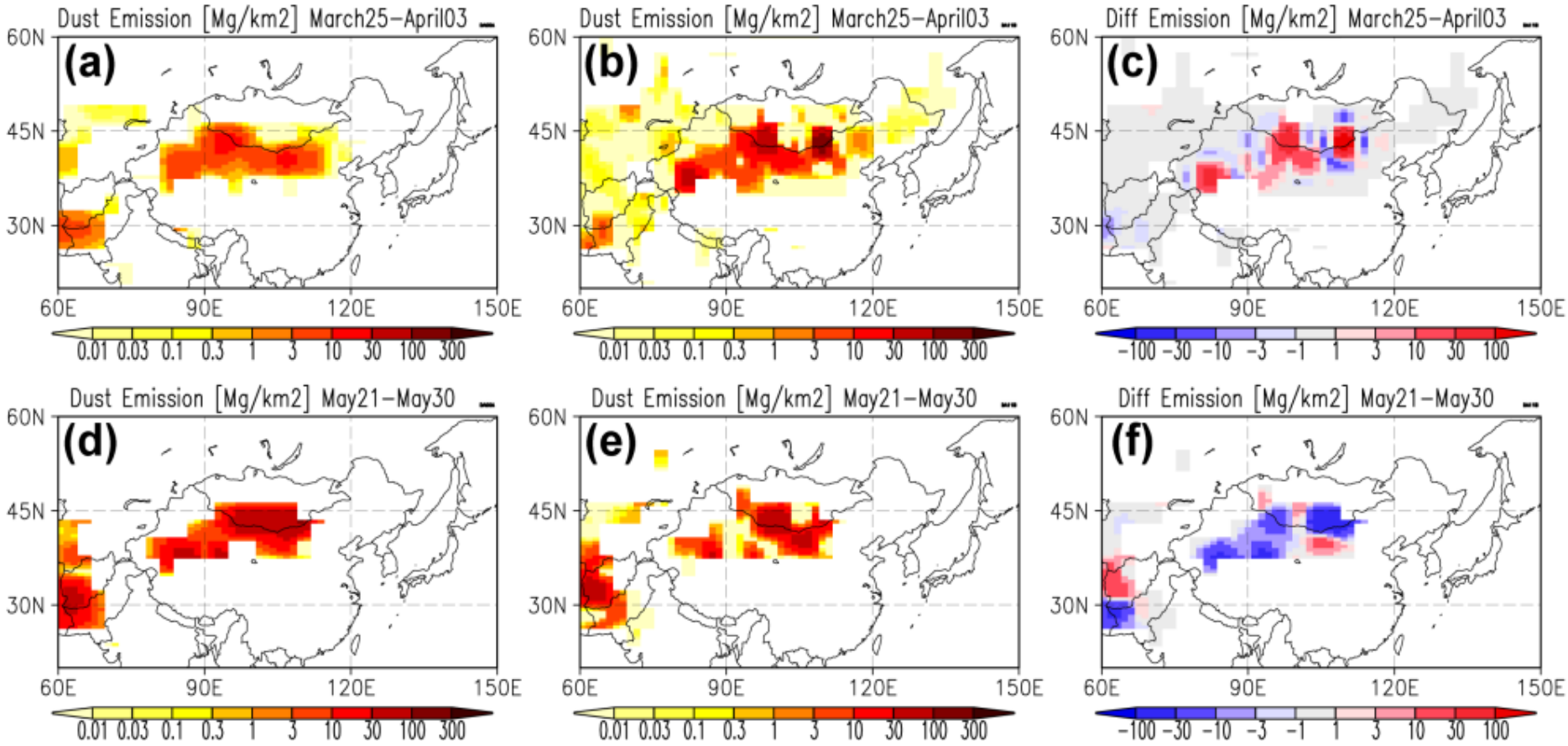
# Summary of OSSE of CALIPSO/CALIOP

- 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



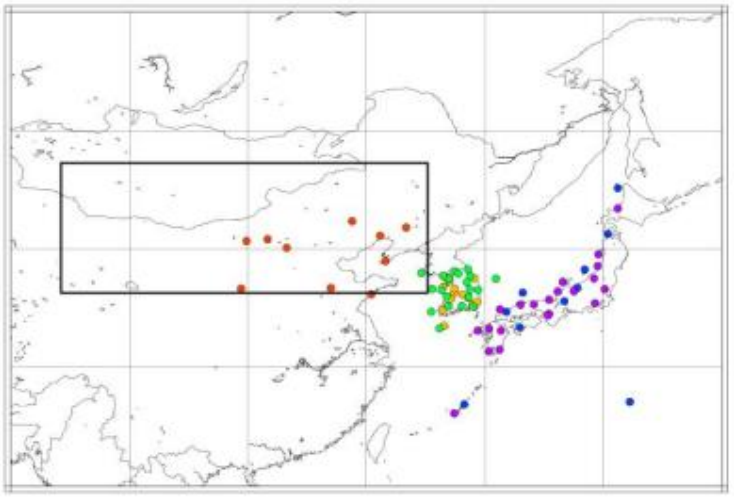

Model estimation

Data assimilation

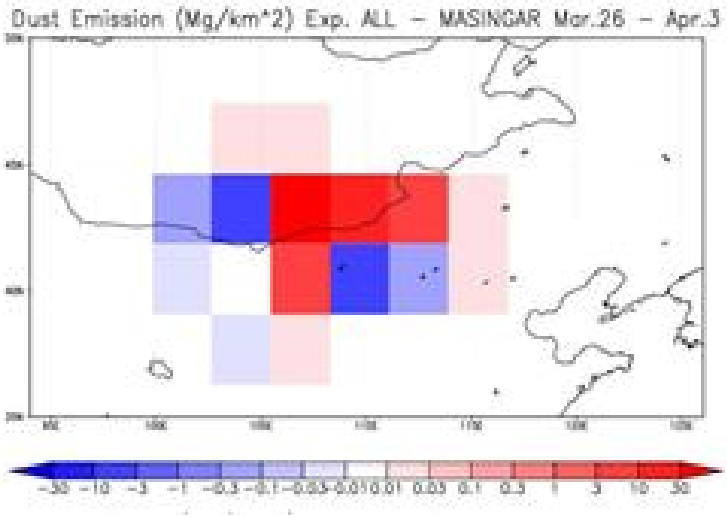
Correction

Sekiyama et al., *SOLA* (2011)

# Inversion analysis of dust emission using Bayesian synthesis



Observation network

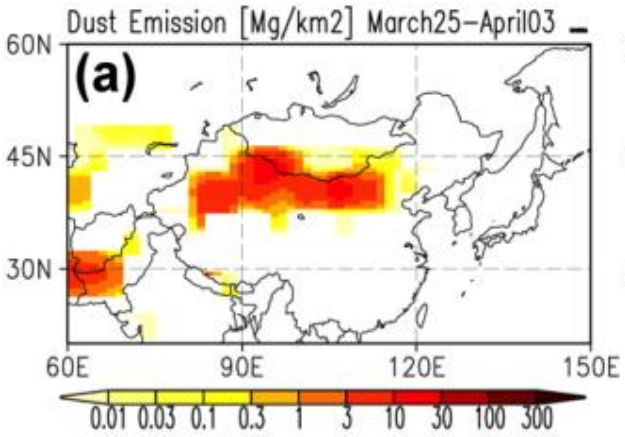



Correction of dust emission

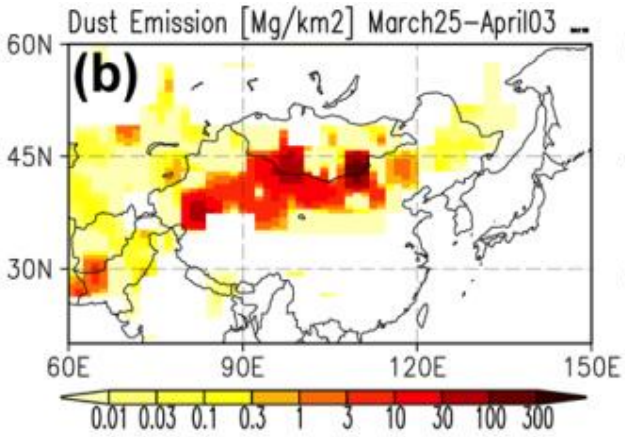
- Inversion analysis by Bayesian synthesis method is applied to dust emission in Asia.
  - ➢ More talk on Wednesday.

# Comparison of inverse analyses of dust emission

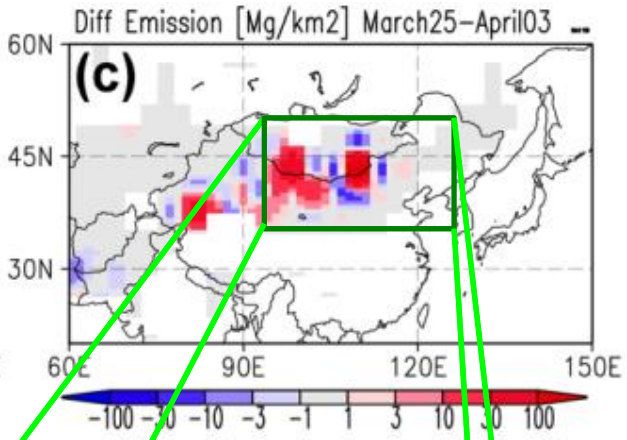
Model estimation




Data assimilation



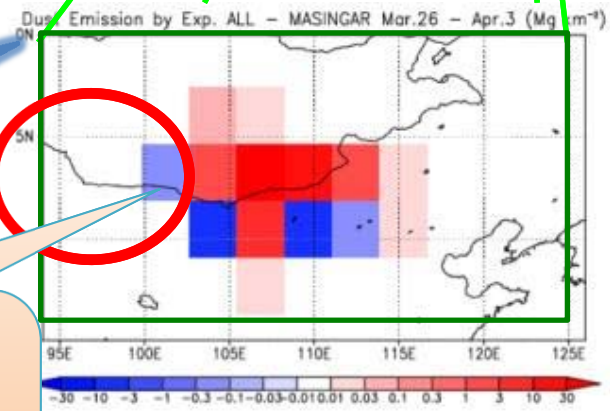

Correction=(b)-(a)




Sekiyama et al., *SOLA* (2011)

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.




Maki et al., *SOLA* (2011)

This is the end of the presentation.

Thank you very much!

Grazie mille.