# Aerosol and Atmospheric Chemistry Modeling and Research in JMA and MRI

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# Topics

- Current state of operational aerosol and atmospheric chemistry modeling in JMA
- Observation, modeling, and data-assimilation
  -Research activity in MRI-
- Comments on observability and requirements for data assimilation and verification

# Operational Atmospheric Environmental Model in JMA

- Global Aerosol Model

  Dust Aerosol ➡ Dust forecast since 2004

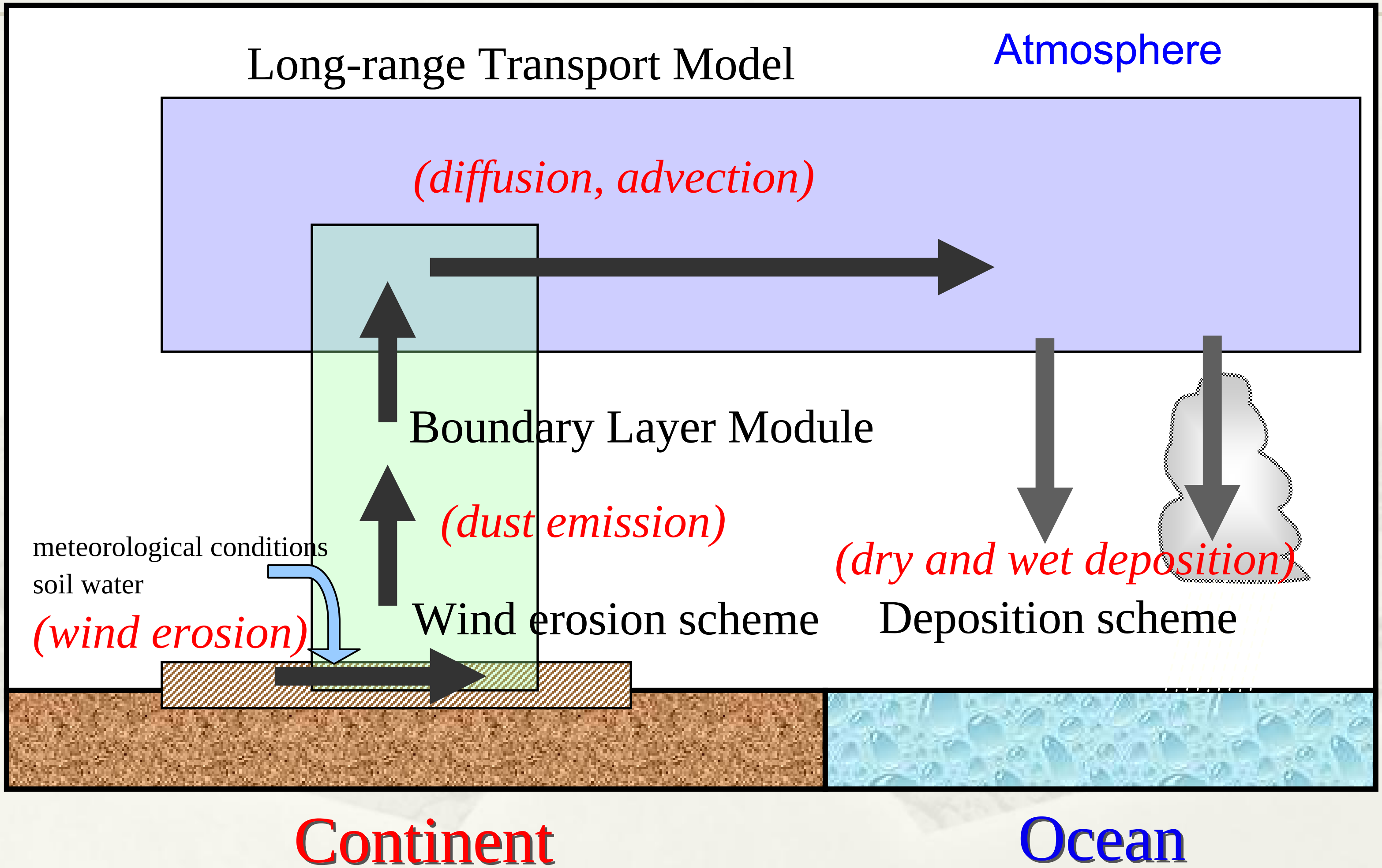
- Global Atmospheric Chemistry Model

  Tropospheric Ozone ➡ Oxidant forecast from 2010

- Global $CO_2$ Model ➡ Information of $CO_2$ distribution

# JMA/MRI dust model: MASINGAR

(Model of Aerosol Species IN the Global AtmospheRe)




MASINGAR is developed in MRI (Tanaka et al., 2003) to study the atmospheric aerosols (MD, BC, SS, S) and related trace species.

# Global Aerosol Model: MASINGAR/MRI Version

- Based on MRI-GCM-CTM
  > T42L30~T106L32 spectral model
- 4 aerosols: Mineral dust(MD), Acid sulfate(AS), Sea salt(SS), Carbonaceous(CB), and Insoluble(IS)
- Physical processes
  >vertical transport with turbulence, cumulus convection, gravitational sedimentation, rain washout
  >dry and wet depositions
- Dust particle size: 10 bins from 0.1 to 10 μm
- Surface (Vegetation, Soil water, Snow cover), Land use, Texture, PSD
- Dust Emission: Saltation Bombardment > Saltation → Dust emission

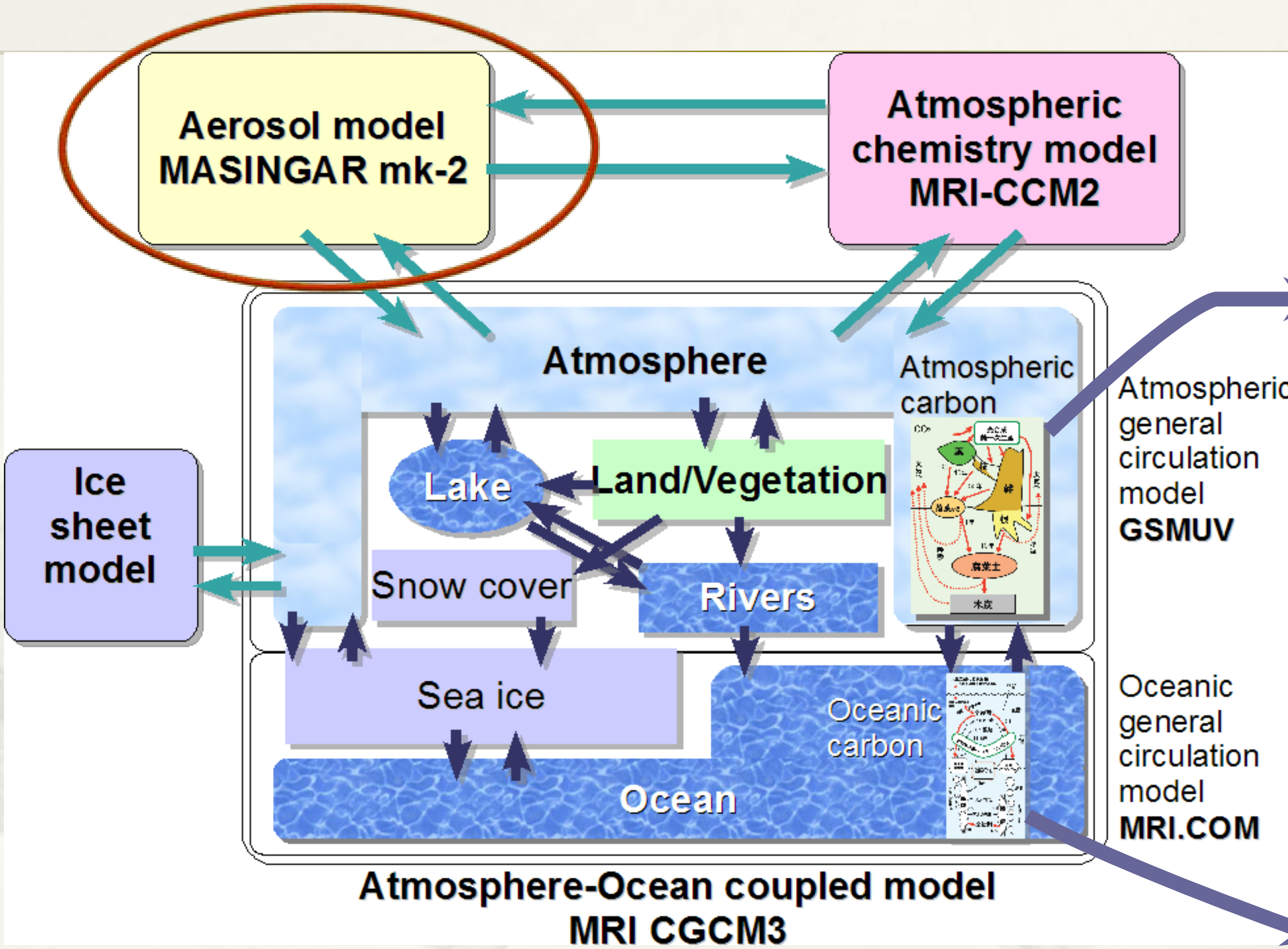
$$\tilde{Q}(D) = \frac{c_s(D)\rho u_*^3}{g}\left(1 - \frac{u_{*t}(D)^2}{u_*^2}\right)$$

where $$c_s(D) = 0.25 + \frac{v_g(D)}{3u_*}$$

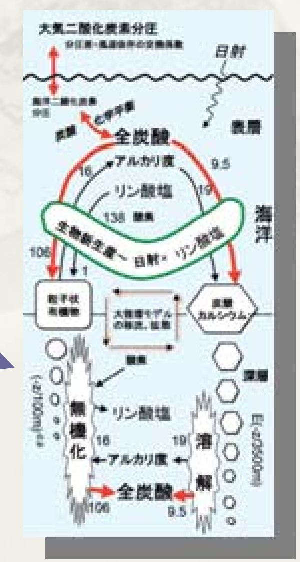
$$Q = \int_0^\infty \tilde{Q}(D)\, p_m(D)\, \mathrm{d}D$$

$$\tilde{F}(D_s, D_d) = \frac{2}{3}\frac{\rho_p}{\rho_a}\frac{\beta\gamma}{u_{*t}(D_d)^2}\tilde{Q}(D_s)$$

# The MRI Earth System Model




Carbon cycle model



The model components are connected using a coupler library called SCUP.

# Dust Forecast Model: MASINGAR/JMA Version

| | |
|---|---|
| Atmospheric Model | MRI/JMA98AGCM (Shibata et al., 1999) |
| Dynamics | General Circulation Model (Spectral Model) |
| Resolution | T106 (1.125º), L30 (~0.4 hPa) |
| Time Integration | Semi-implicit Scheme |
| Cumulus Convection | Arakawa-Schbert Scheme |
| Radiation | 2 Stream (Shibata) |
| Surface Processes | SiB |
| Turbulent Diffusion | Mellor-Yamada (Level 2 Closure) |
| Nudging | Meteorological analysis, forecast, and snow depth analysis |

| | |
|---|---|
| Model name | MASINGAR (Tanaka et al., 2003, 2005) |
| Dust bin size | 10 bins (0.2 ~ 20 μm) |
| Emission | Gillet Scheme (see below) |
| Transport | 3D-Semi Lagrangian Scheme |
| Diffusion | Turbulent and cumulus convection |
| Deposition | Dry and Wet Deposition |

$$F = CMA\frac{W_{gt} - W_g}{W_{gt}}(U_{10} - U_t)\,U_{10}^2 \quad \text{for} \quad U_{10} > U_t$$

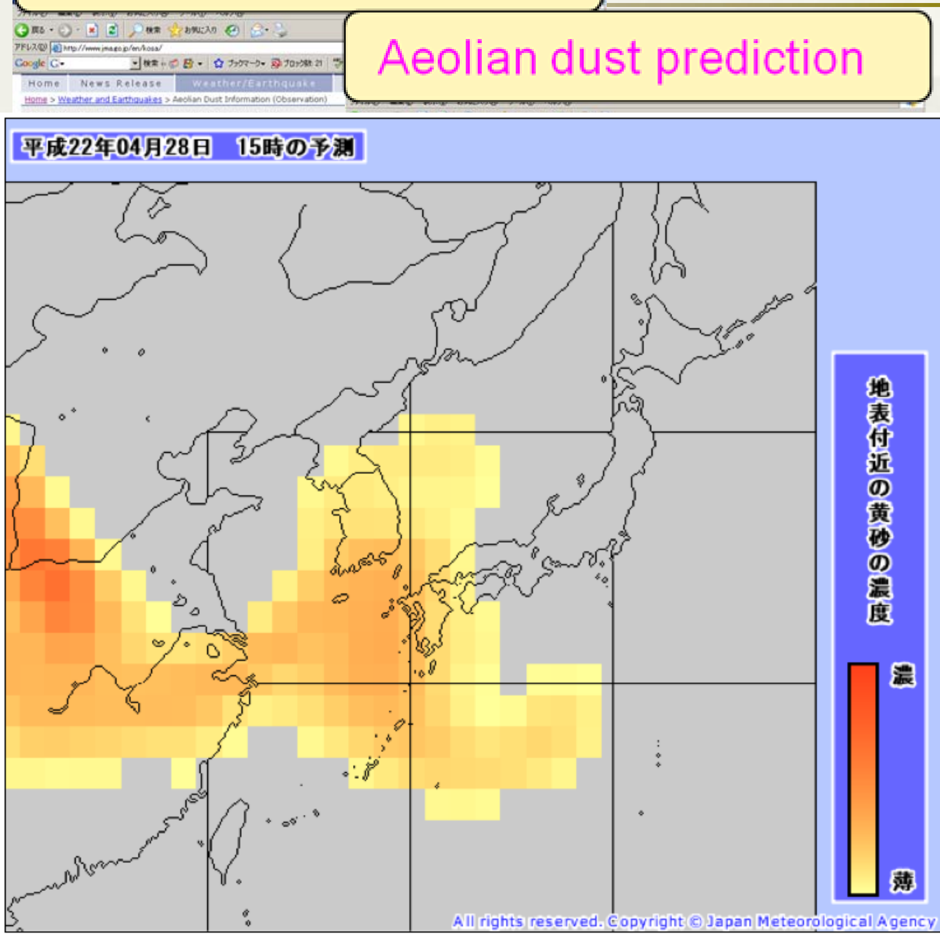
$F$: dust emission flux,
$C$: dimensional factor,
$M$: mass distribution,
$A$: erodible fraction,
$W_g$: soil moisture,
$W_{gt}$: threshold value of $W$g (0.3kg/m$^2$),
$U_{10}$: wind velocity at 10m,
$U_t$: threshold wind speed (6.5m/s, 10m)

Dust emission flux depends on the surface conditions (vegetation, snow cover and soil moisture) and the surface wind speed.

# JMA's activities on Asian dust

Aeolian dust observation

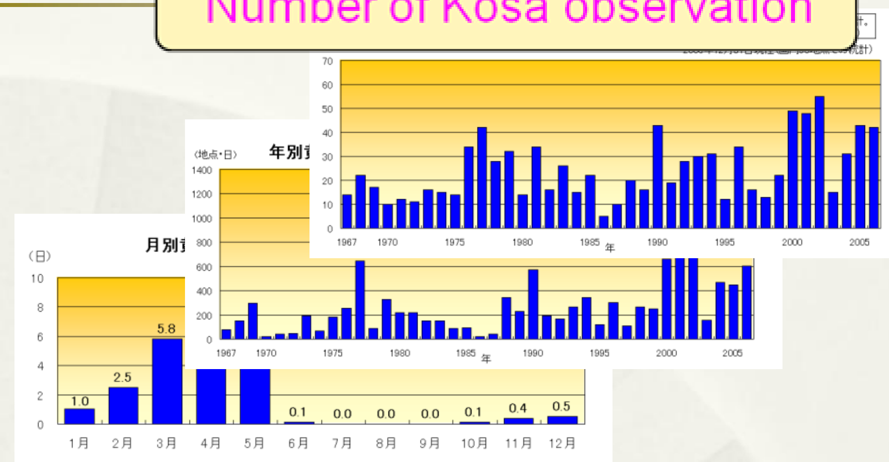
Aeolian dust prediction



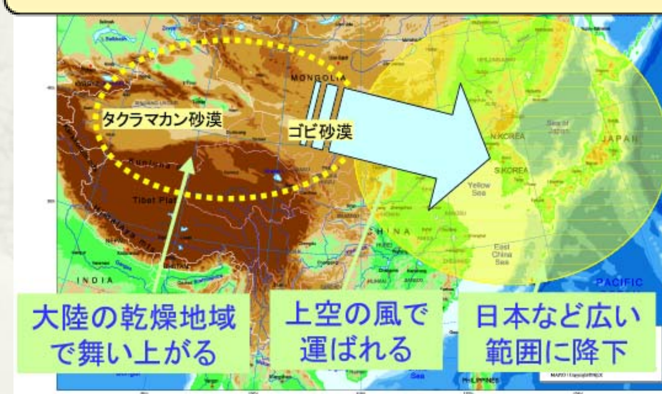

(when needed)

Japanese only

Number of Kosa observation




Basic information of Kosa




JMA have been providing the Aeolian dust information since January 2004.
MRI have been developing the numerical dust aerosol model .

# Chemical Transport Model in JMA

| | |
|---|---|
| Forecast | 35 long-lived species, 14 short-lived species |
| Chemical Reaction | 79 Gas phase reactions, 34 Photolysis, Type I and II PSC, Salfate aerosol |
| Heterogeneous Reaction | 6 types of PSC, 3 types of Salfate aerosols |
| Boundary Condition | Surface concentration of $N_2O$, $CH_4$, $CO_2$, CO, $No_y$, $CCl_4$, $CFCl_3$, $CF_2Cl_2$, $CH_3Cl$, $CH_3Br$, $CF_2ClBr$, $CF_3Br$, and CCly |
| Advection | 3-D Semi-Lagrangian (Long-lived species) |
| Vertical diffusion | Turbulent diffusion |
| Surface deposition | Consider deposition velocity for $O_x$ |
| Wet deposition | Consider precipitation scavenging for $HNO_3$, HCl, and HBr |
| Nudging | Total $O_3$（NASA/OMI） |
| Reference | Shibata et al, 2005 |

Atmospheric part is the same as MASINGAR

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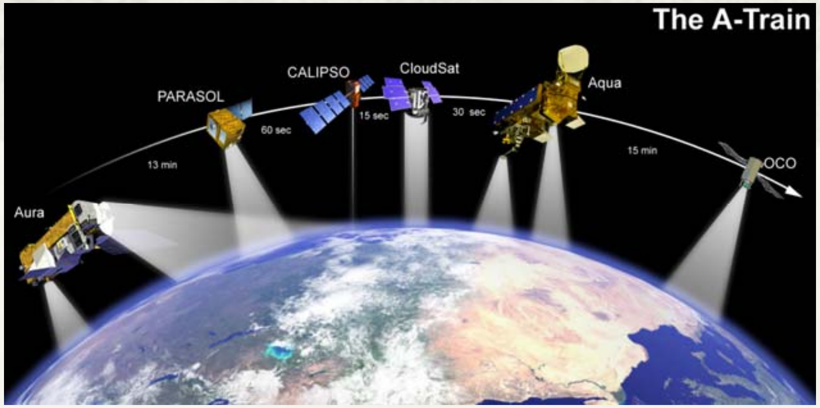
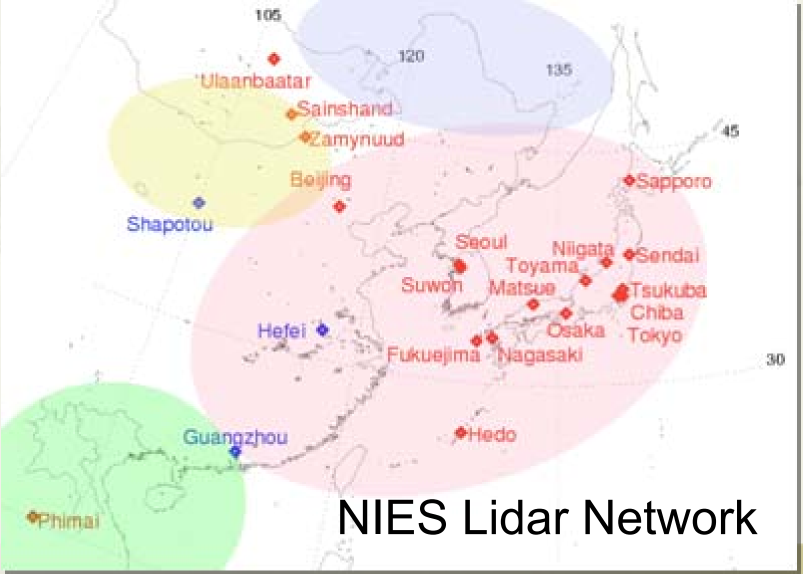
- Comments on observability and requirements for data assimilation and verification

# Aerosol data assimilation

- *Aerosol observation:*
  Available data are very sparse! Spatio-temporally, both ground-based and satellite data
- *Model simulation:*
  useful, but not real! (it's virtual reality)
- *Data assimilation:*
  It's a fusion of observation and simulation with powerful and highly informative techniques.




CALIOP/CALIPSO



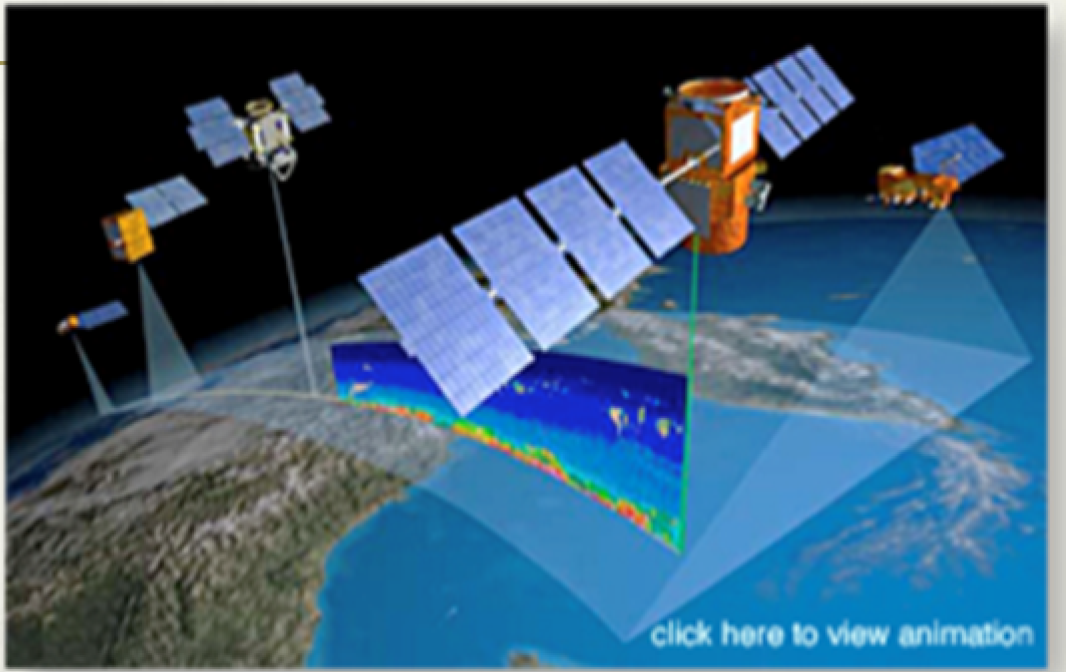

NIES Lidar Network

# 4-Dimensional Ensemble Kalman Filter

| | 4D-Var | 4D-EnKF |
|---|---|---|
| Background error statistics | Flow-dependent | Flow-dependent |
| Program code | Complicated | **Simple** |
| Adjoint matrix | Necessary | **Unnecessary** |
| Observation operator | Requires tangent linear & adjoint operators | **Requires only a forward transformation** |
| Asynchronous observations | Handles at each observational time | Handles at each observational time |
| Analysis error covariance | Not provided | **Explicitly provided** |

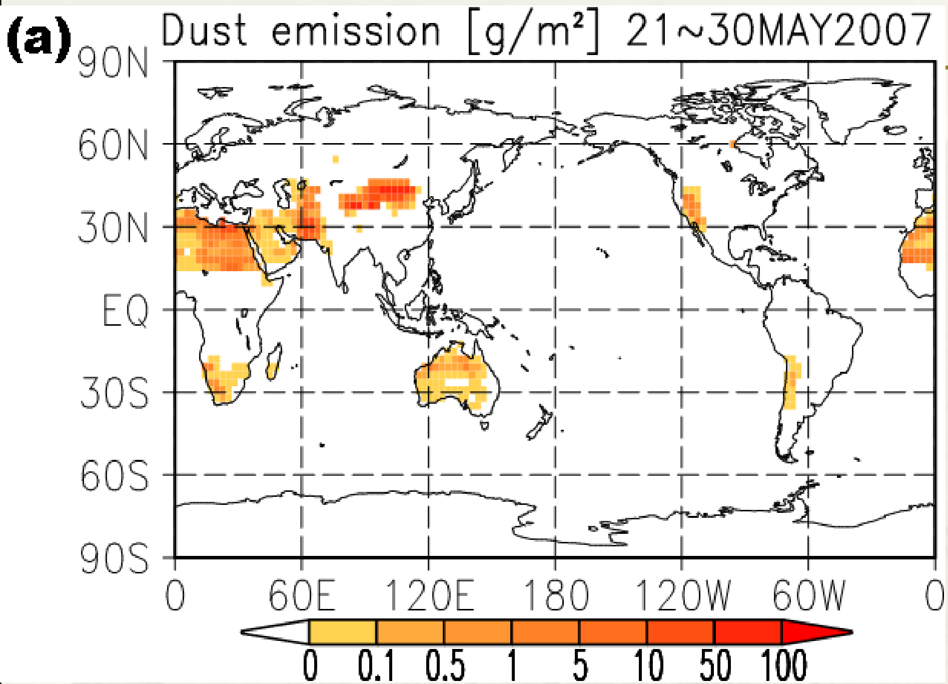
# Satellite Lidar Observation (CALIPSO)

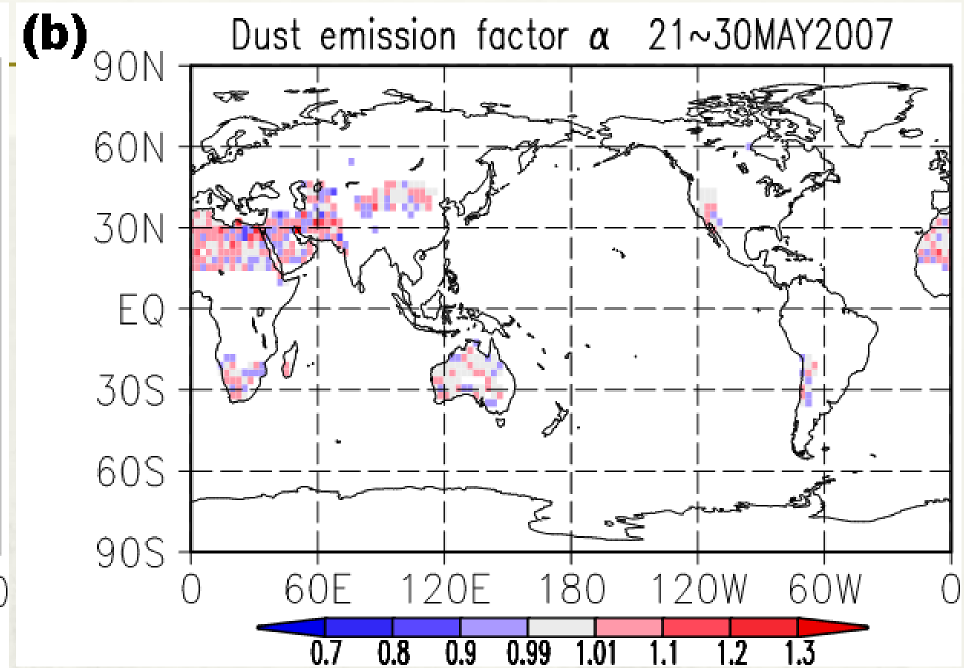
- CALIPSO , launched in April 2006 by NASA, is the first satellite that carries a lidar instrument optimized for aerosol.
- CALIPSO is in a 705-km polar orbit with a 16-day repeat cycle as part of the NASA A-train.
- The polar orbit has a 1000 km longitudinal interval per day at mid-latitudes, with the swath width of zero degrees.




**LIDAR** (**Li**ght **D**etection **A**nd **R**anging): optical remote sensing technology that measures properties of scattered light to find information of distant particles, like the radar technology which uses radio waves.

# Results (Dust Flux Distribution)




$\boldsymbol{F^*(x, t) = \alpha F(x, t)}$, where grid *x* and time *t*.

(a) Dust emission intensity *F(x, t)* generated by MASINGAR without any assimilation

(b) the correction factor $\alpha$ estimated by the EnKF assimilation. All 10 size bins of dust aerosol are accumulated and averaged from 21 to 30 May 2007.

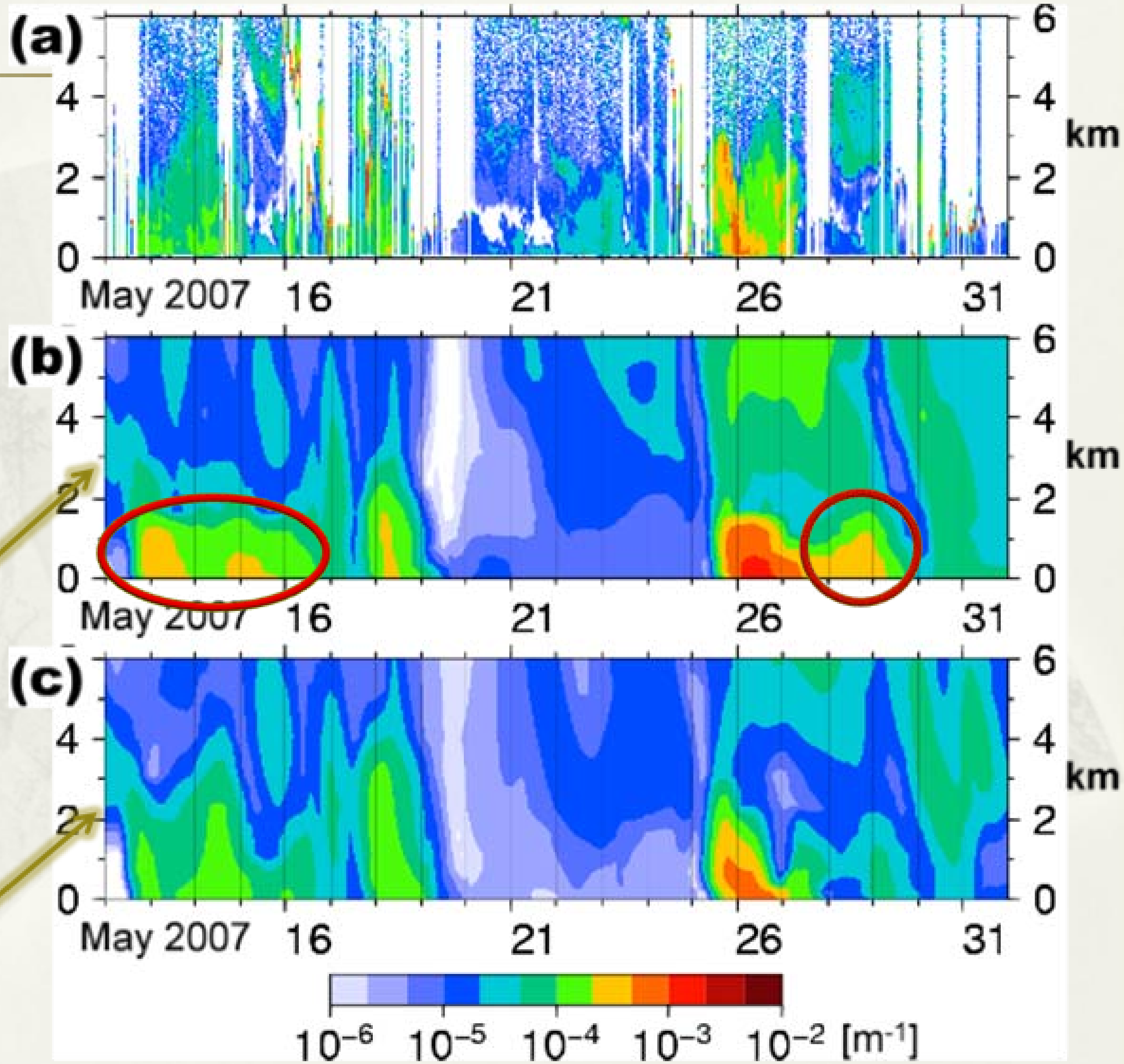
# Results (comparison with a ground-based lidar)

Observed and simulated extinction coefficients at 532nm for non-spherical particles (≈ dust aerosol) at 133ºE/35ºN.
(X-axis: date, Y-axis: altitude in km)

(a) Independent ground-based lidar observation

(b) free model run result without assimilation

(c) data assimilation result with CALIPSO data.






(Sekiyama et al., 2009 ACP)

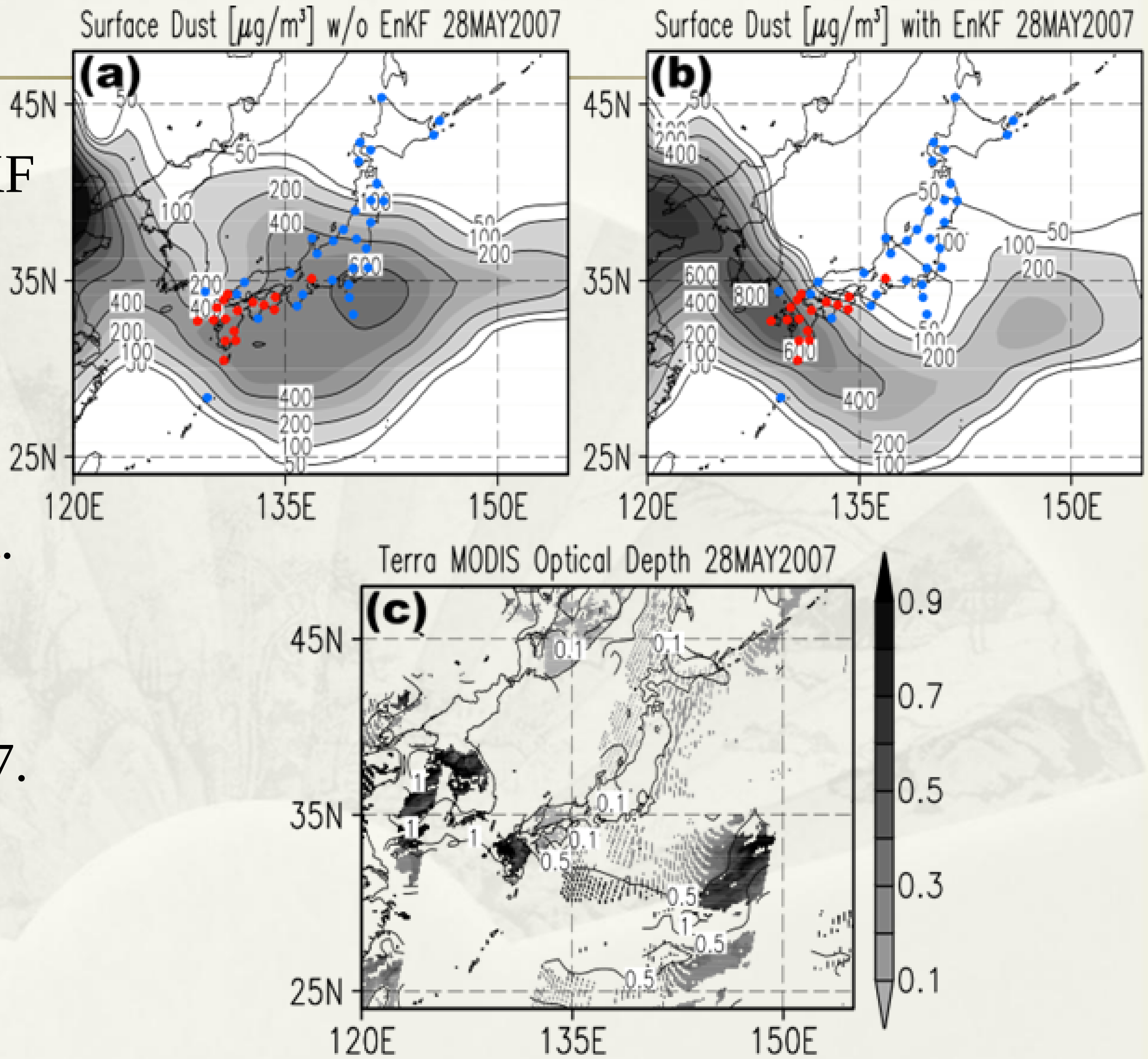
# Results (comparison with weather reports)

(a) Free model run w/o EnKF

(b) Analysis of 4D-EnKF assimilation.

Red points show weather stations observed dust event. Blue did not.

(c) MODIS OT on 28May07.

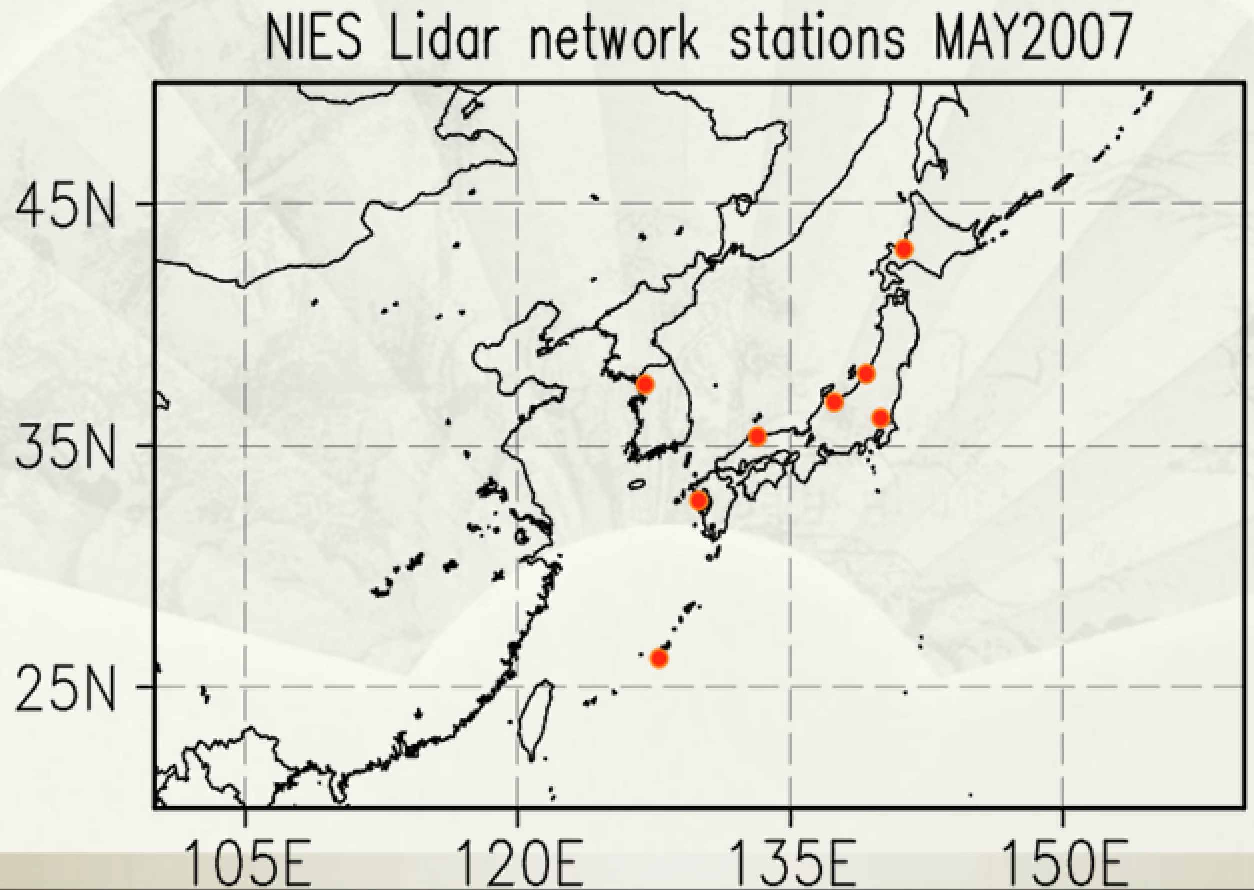


# Data assimilation experiment using operational Lidar network by NIES

Same information as CALIOP/CALIPSO

Less spatial information: sparsely located sites (far from source region)

Continuous temporal information compared to CALIOP



## Results by AOT

13 May 2007

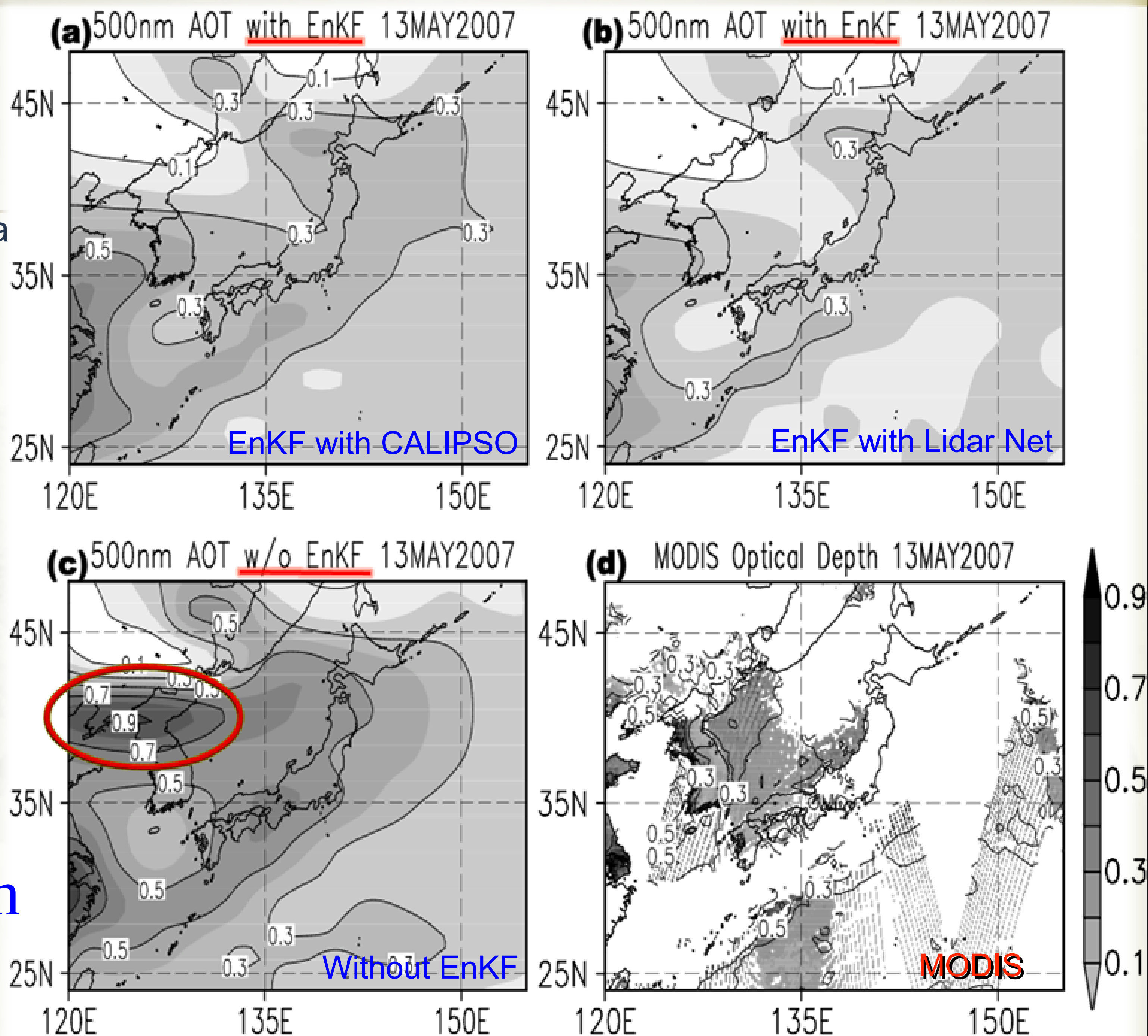
(a) CALIPSO data assimilation

(b) NEIS-Lidar data assimilation

(c) without data assimilation

(d) NASA/MODIS Optical Depth

Lack of Validation Data !



# Summary of EnKF

- The 4D-EnKF assimilation system was successfully performed a one-month experiment in May 2007 with CALIPSO aerosol observations.
- The assimilation results was validated by independent dust observations in East Asia: a ground-based LIDAR and weather reports of aeolian dust events.
- This assimilation system can potentially provide global aerosol reanalyses for various types and sizes.
- The reanalyses contains not only aerosol concentrations in the atmosphere, but also the dust emission intensity.

# Dust observation in East Asia

**1. Various Dust-related observation networks and new satellites**

Operational: Routine Met., GAW, KMA-CMA PM10Net...

Research Base: EANET, AD Net, SKYNET...

Intensive site: Hedo, Fukue... → No Standard!

**2. Physical process monitoring (Research use)**

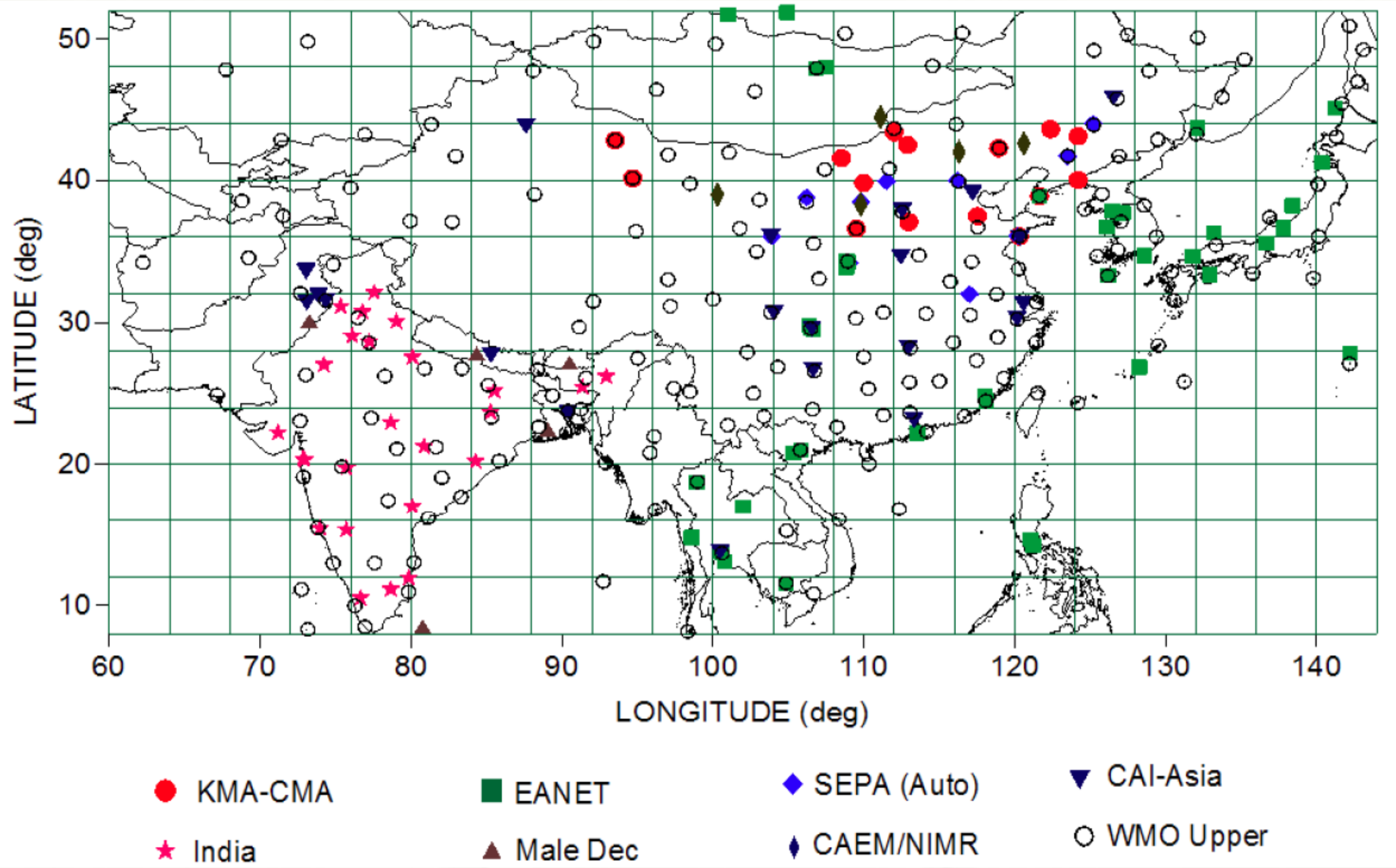
Emission and deposition (*Mikami* et al., validation of model)

**3. Network of Network**

TEMM/UNEP DSS forecast and early warning system

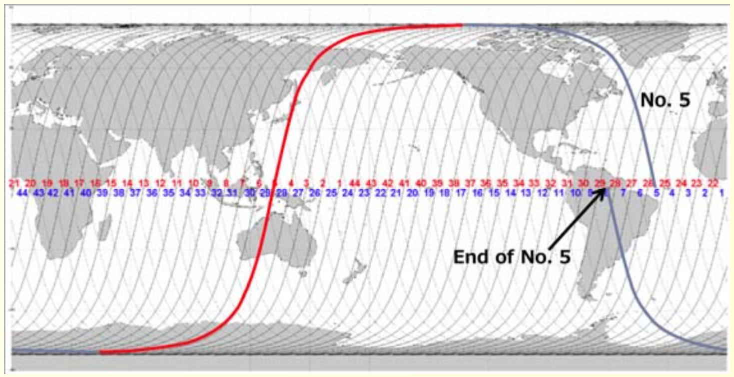
WMO SDS-WAS Asian Regional Center
→ cooperation and linkage with research community.

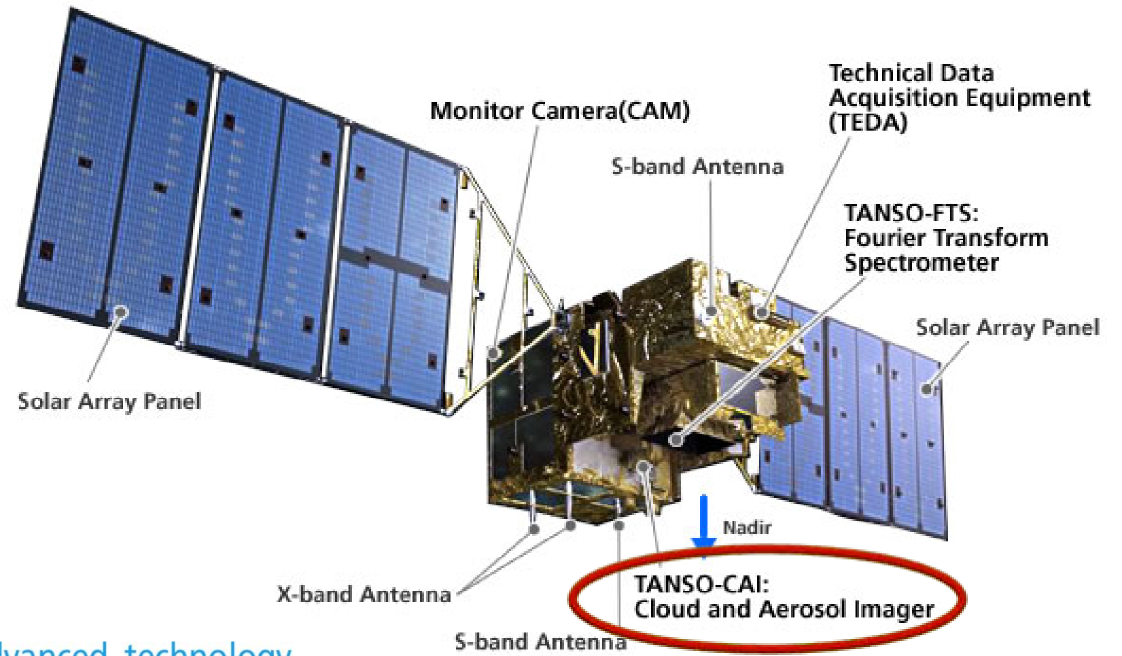
# Various Dust-related observation networks in Asia




(S-U Park)

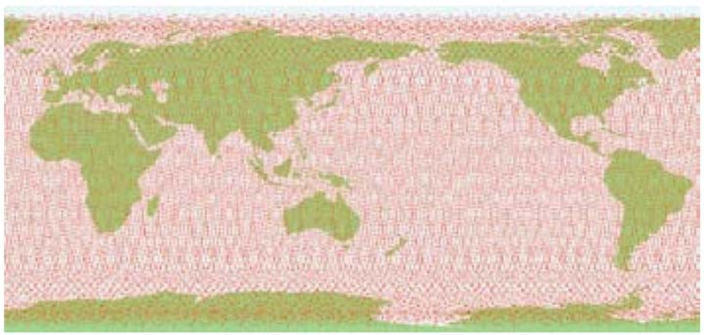
**GOSAT TANSO-CAI** Cloud Aerosol Imager
Cloud Properties, Aerosol Properties (AOT, SSA, Phase Function of each aerosol type)




**Highly accurate observation realized through advanced technology**

IBUKI is equipped with a greenhouse gas observation sensor (TANSO-FTS) and a cloud/aerosol sensor (TANSO-CAI) that supplements TANSO-FTS. The greenhouse gas observation sensor of IBUKI observes a wide range of wave lengths (near infrared region ~ thermal infrared region) within the infrared band to enhance observation accuracy. The number of observation channels is as large as approx. 18,500. A cloud/aerosol sensor observes clouds and aerosol that can be a factor leading to errors in the measurement of greenhouse gas in order to improve greenhouse gas observation accuracy.



「いぶき」の観測点(標準モード5万6千点)
Observation points of IBUKI (56,000 points in standard mode)

and EarthCARE(2013), GCOM-C1/SGLI (2013)....

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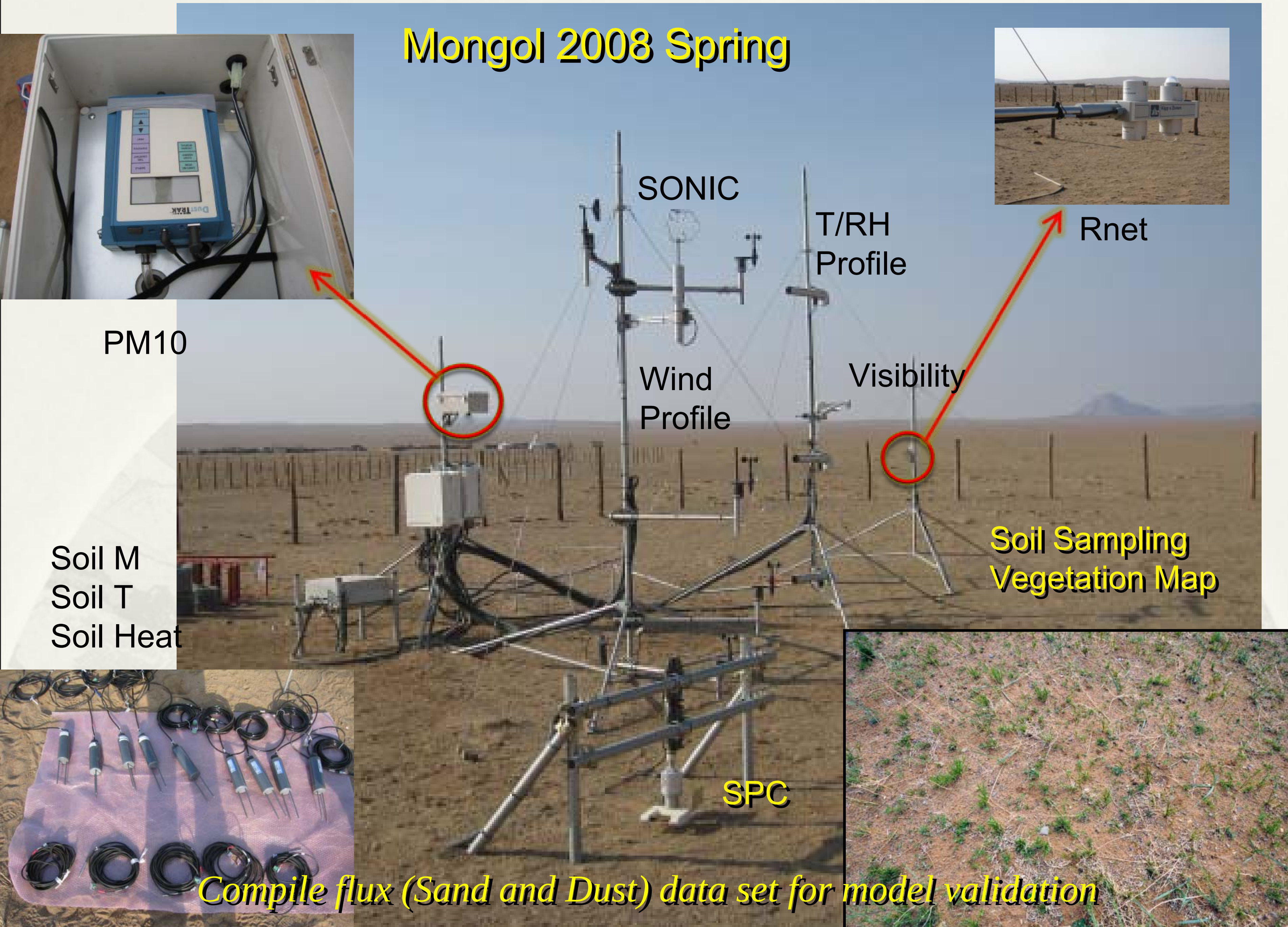
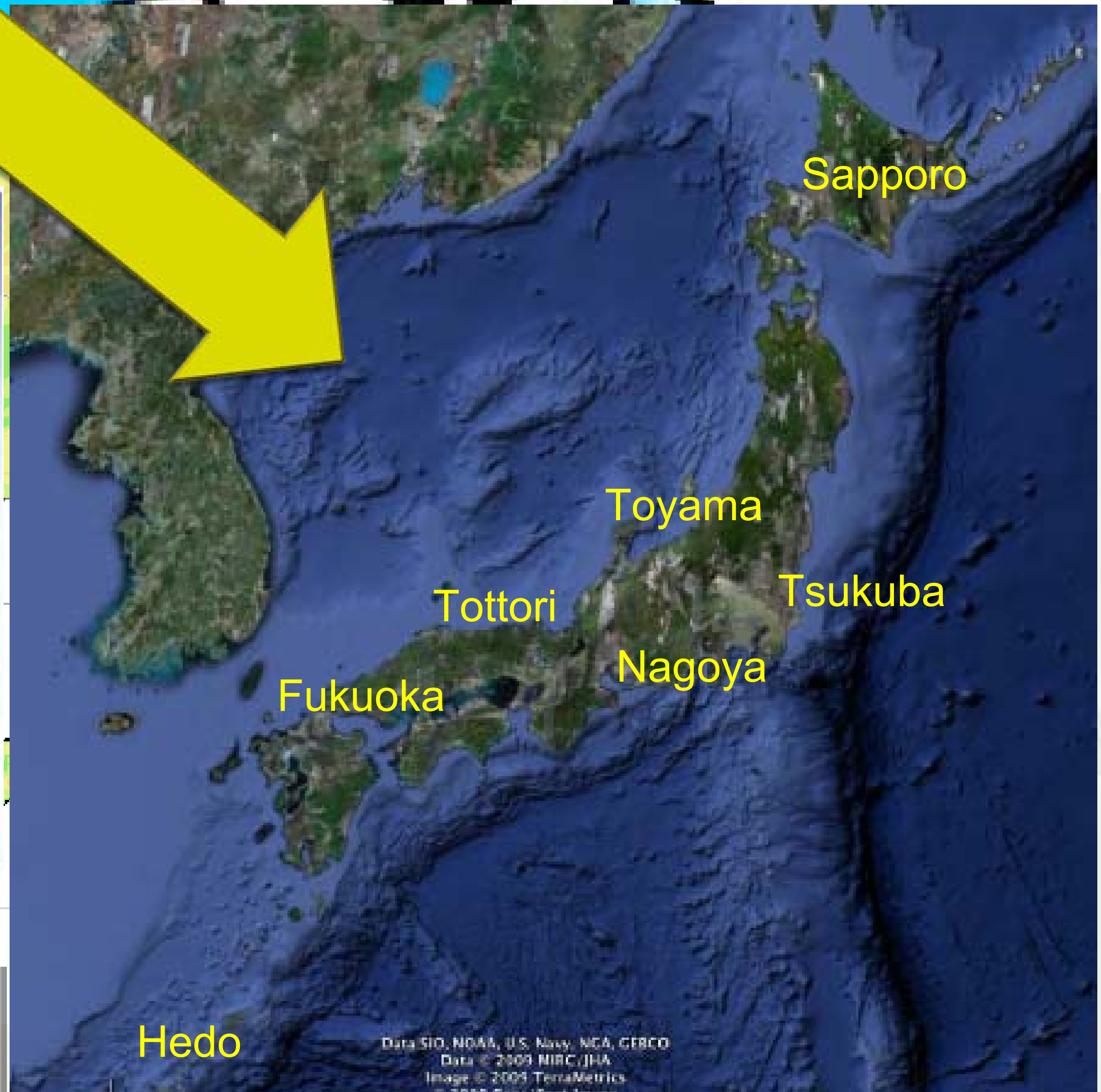
# Mongol 2008 Spring




*Compile flux (Sand and Dust) data set for model validation*

# DRAEMON

(DRY AND WET DEPOSITION MONITORING NETWORK)


Validation data set for dust deposition

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# Discussion

**1. EnKF proved to be useful for aerosol data assimilation**

*Our results clearly proved the availability of EnKF for dust model.*
*EnKF is useful for aerosol data assimilation (better than 4D-Var).*

**2. Great availability of Satellite information for aerosol data assimilation**

*CALIOP/CALIPSO proved to be effective for model improvement.*
*Use of new satellite information (GOSAT, GCOM-CI, EARTH-CARE) must be helpful.* → *Most of them are research use (non-operational).*

**3. Availability of ground based Lidar network (NIES-AD Net/GALION)**

*NIES Lidar Net (AD Net, 23 sites): Most of them is open for public*
*Data assimilation for long-range transported aerosol* → *GALION*

**4. Data sharing effort for DSS in East Asia**

*We have a lot of ground-based monitoring resources in East Asia.*


Thank you !
Mongol 2009