Data Assimilation of Satellite Lidar Aerosol Observations

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Contents

- Aerosol Simulation
  - Asian Dust Forecasting
- Lidar Observation
  - Lidar Satellite CALIPSO
- Data Assimilation with LETKF
  - Asian Dust Plumes
  - Asian Dust Emission
- Summary and Future Work
  - Next-generation Lidar Satellite

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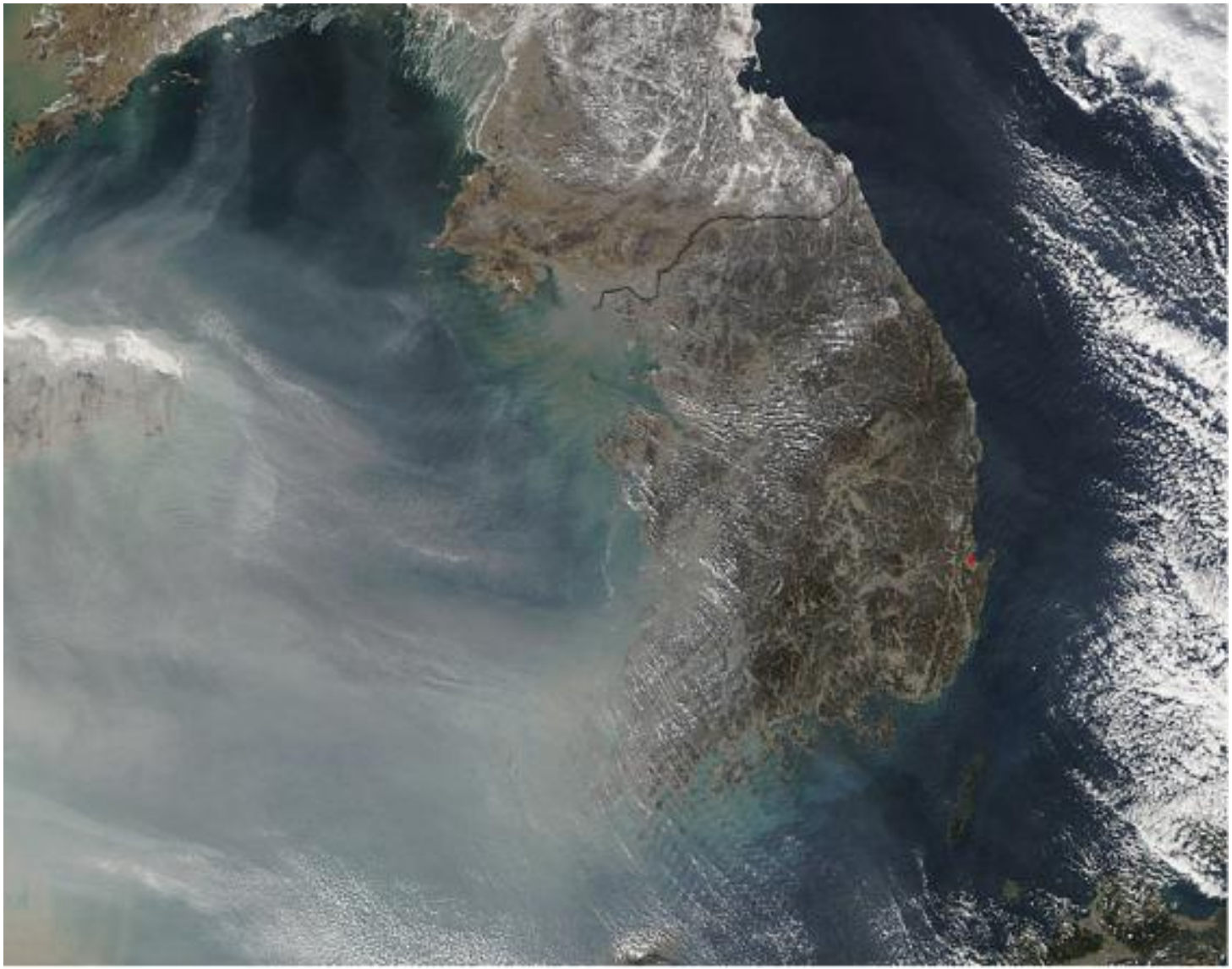
What's Aerosol?

- Aerosol is a suspension of fine solid particles or liquid droplets in a gas.

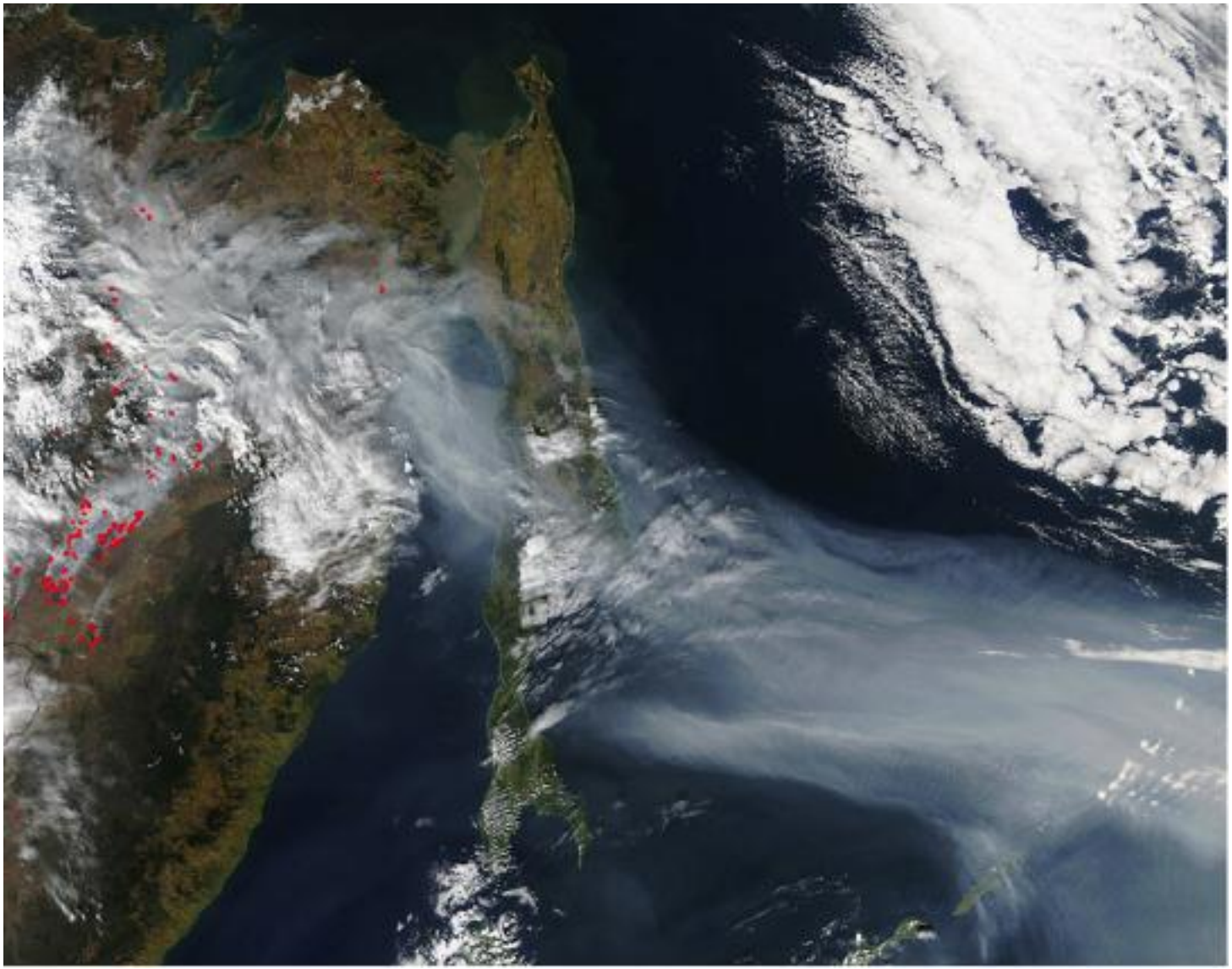
  For example:

  - Clouds
  - Smog (Sulfate, Elemental Carbon, etc.)
  - Smoke (EC, Organic Carbon, etc.)
  - Sea-salt
  - Dust
    - Asian Dust "*Kosa*"
    - Saharan Dust
    - …



Sulfate aerosol from urban areas over Yellow Sea

[photographed by MODIS/NASA]



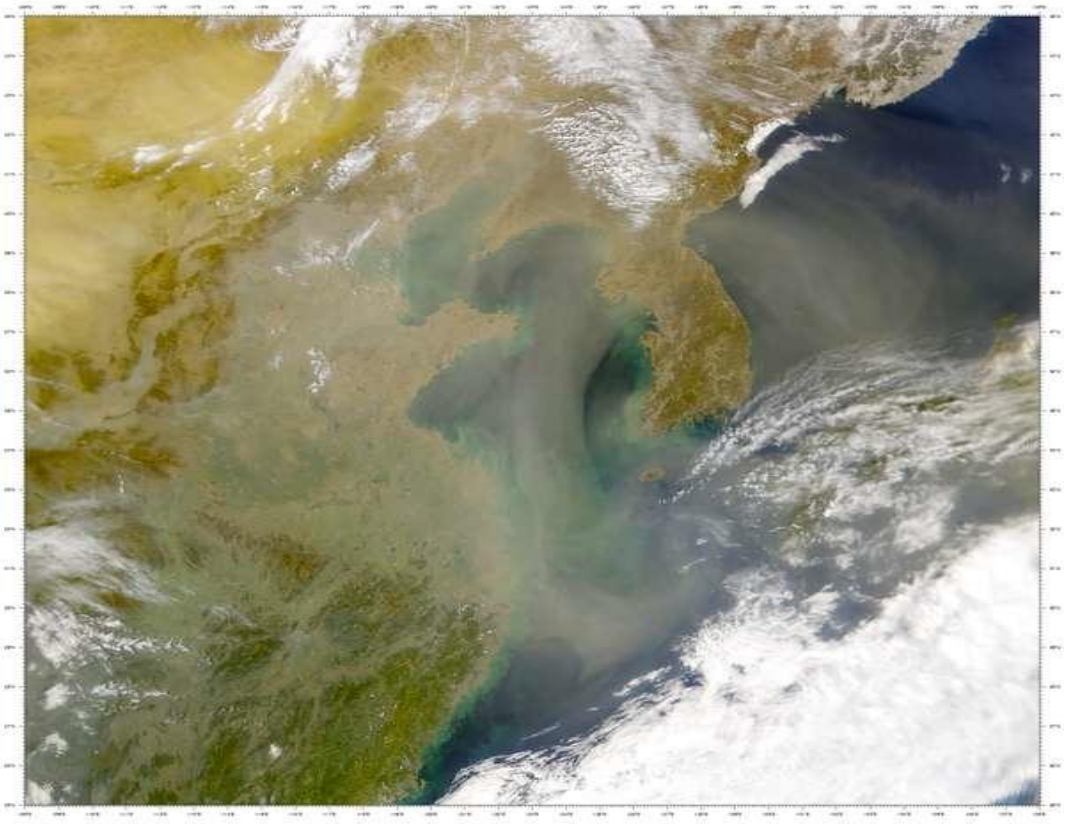
Smoke aerosol from wildfires over Siberia

[photographed by MODIS/NASA]

Dust aerosol over Sahara and Arabian Peninsula

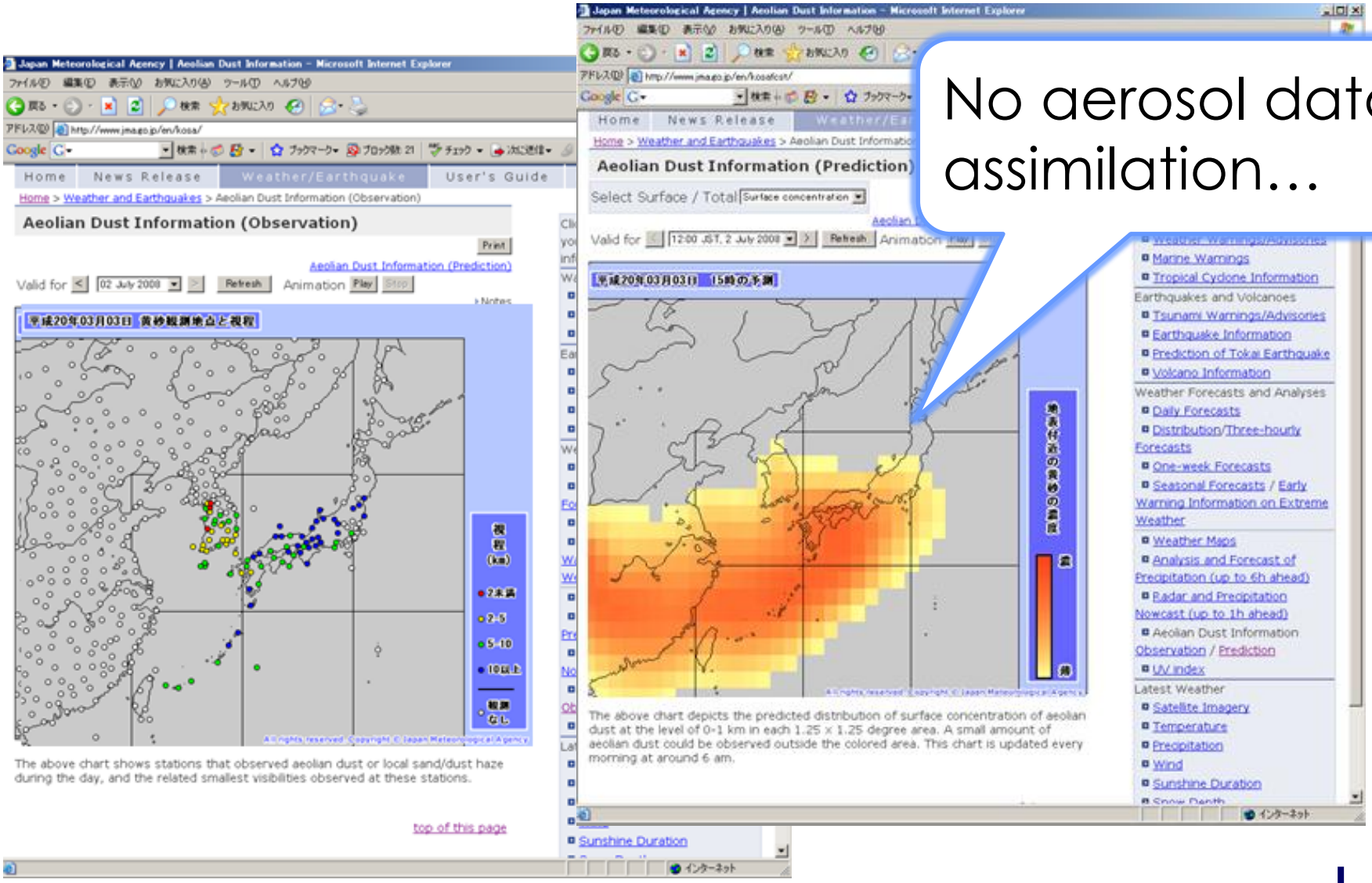
[photographed by MODIS/NASA]

Asian Dust "*Kosa*"



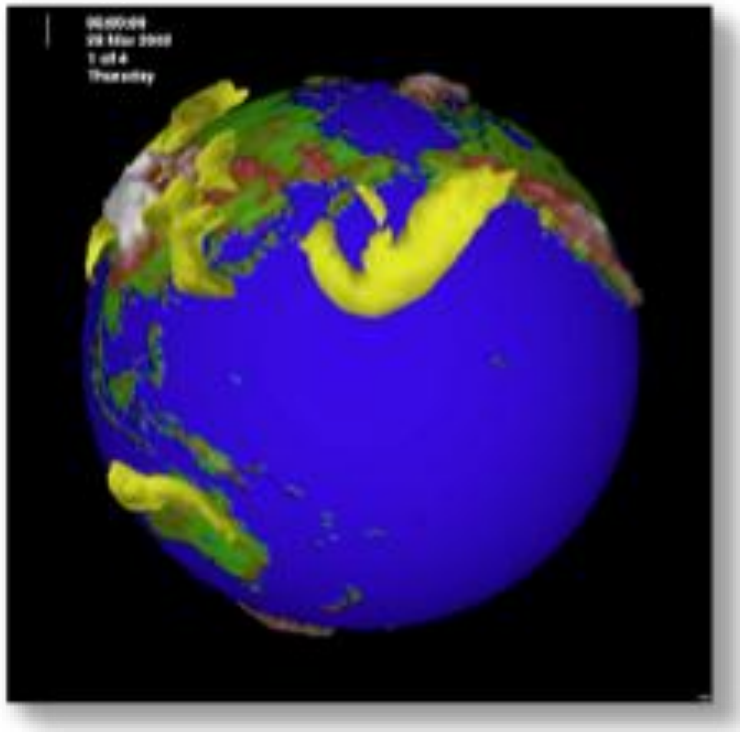
Asian Dust: seasonal phenomenon sporadically affecting East Asian countries during the springtime.

JMA Operational Dust Forecast

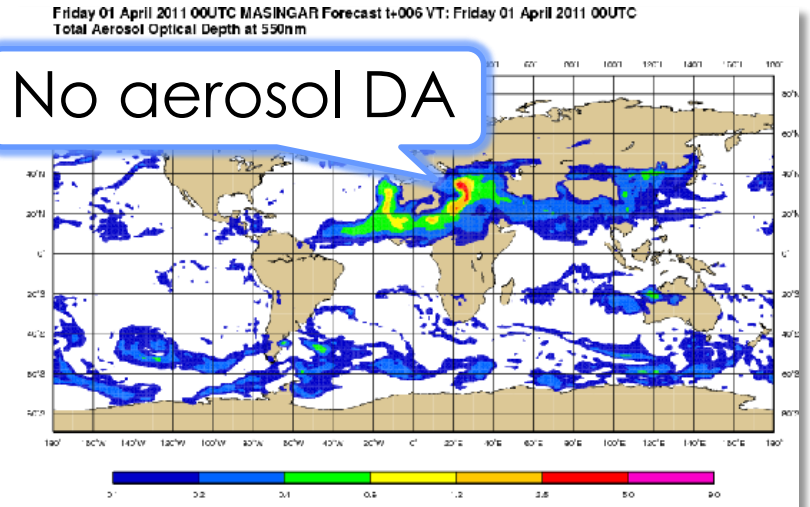


Global Aerosol Model

- The Model of Aerosol Species in the Global Atmosphere (**MASINGAR**) was developed by the MRI/JMA.
- MASINGAR handles **dust** (partitioned into 10-size bins), **sea-salt**, **OC**, **BC**, and **sulfate** aerosols.
- The meteorological components are **nudged** to the 6-hourly JMA analysis or forecast.

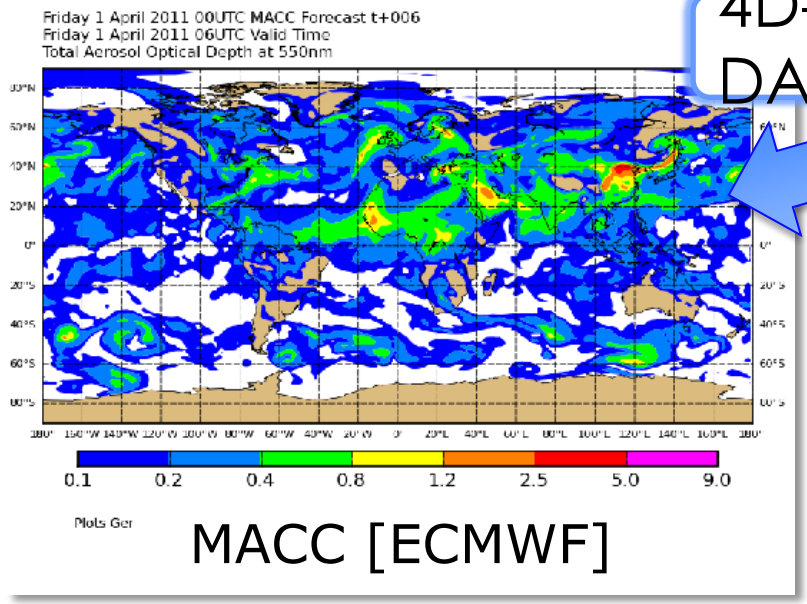


Data Assimilation with MODIS?



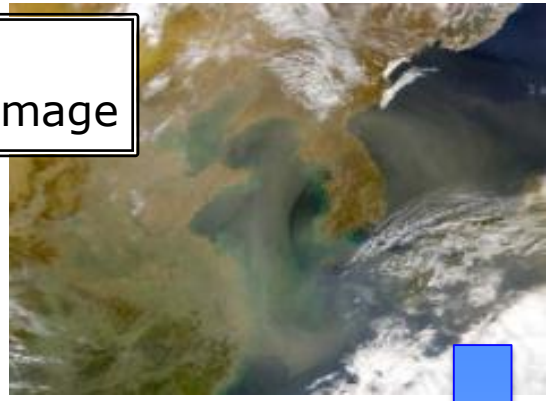
No aerosol DA

MASINGAR [MRI/JMA]

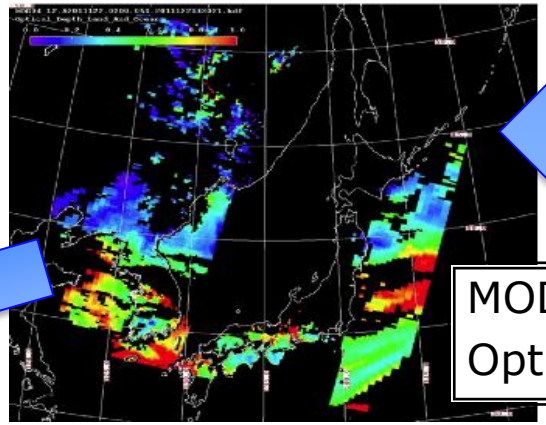


MACC [ECMWF]

4D-Var DA



MODIS Visible Image



MODIS Optical Depth

But MODIS does not have information about the vertical distribution of aerosols…

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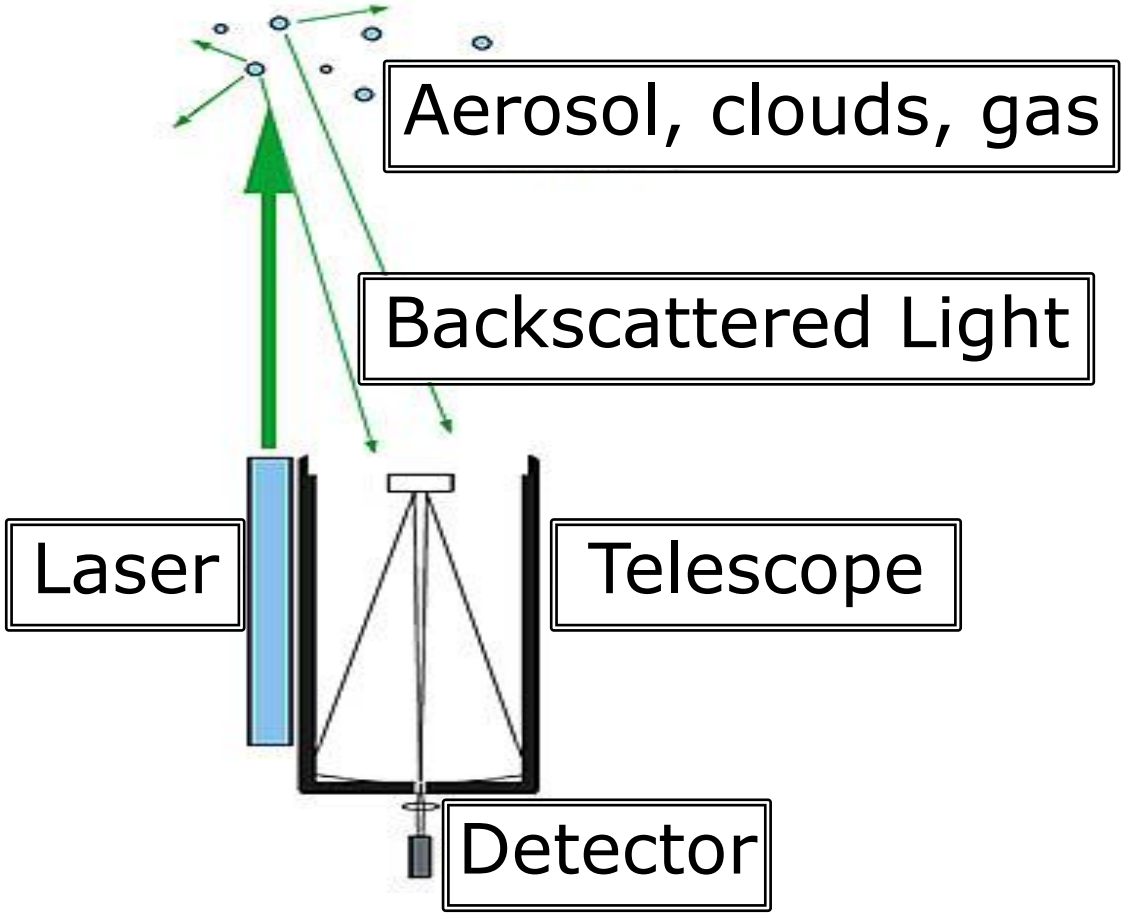
What's Lidar?

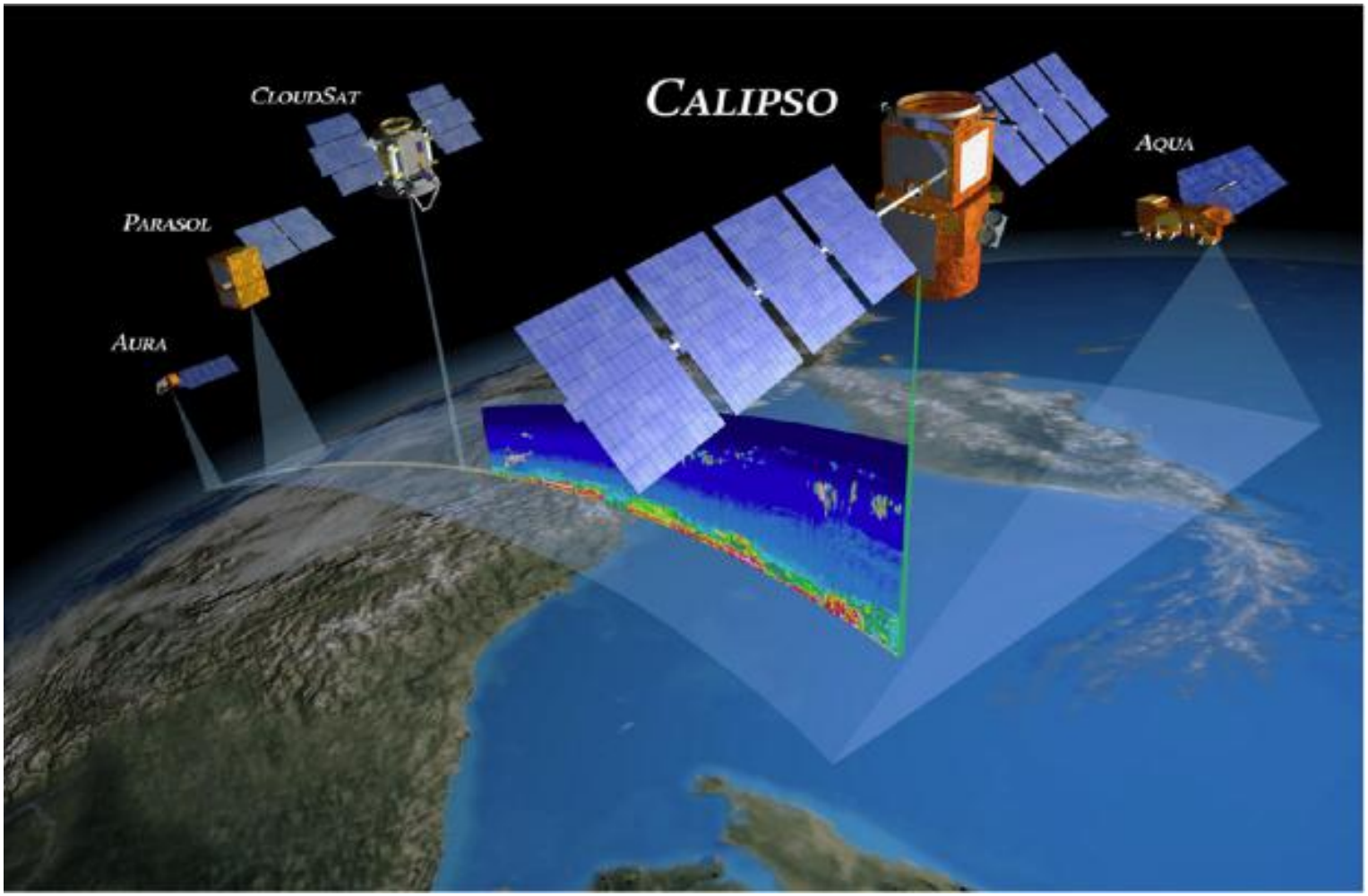
- Lidar (Light Detection And Ranging) is an optical remote sensor with laser light.



Characteristics of Lidar

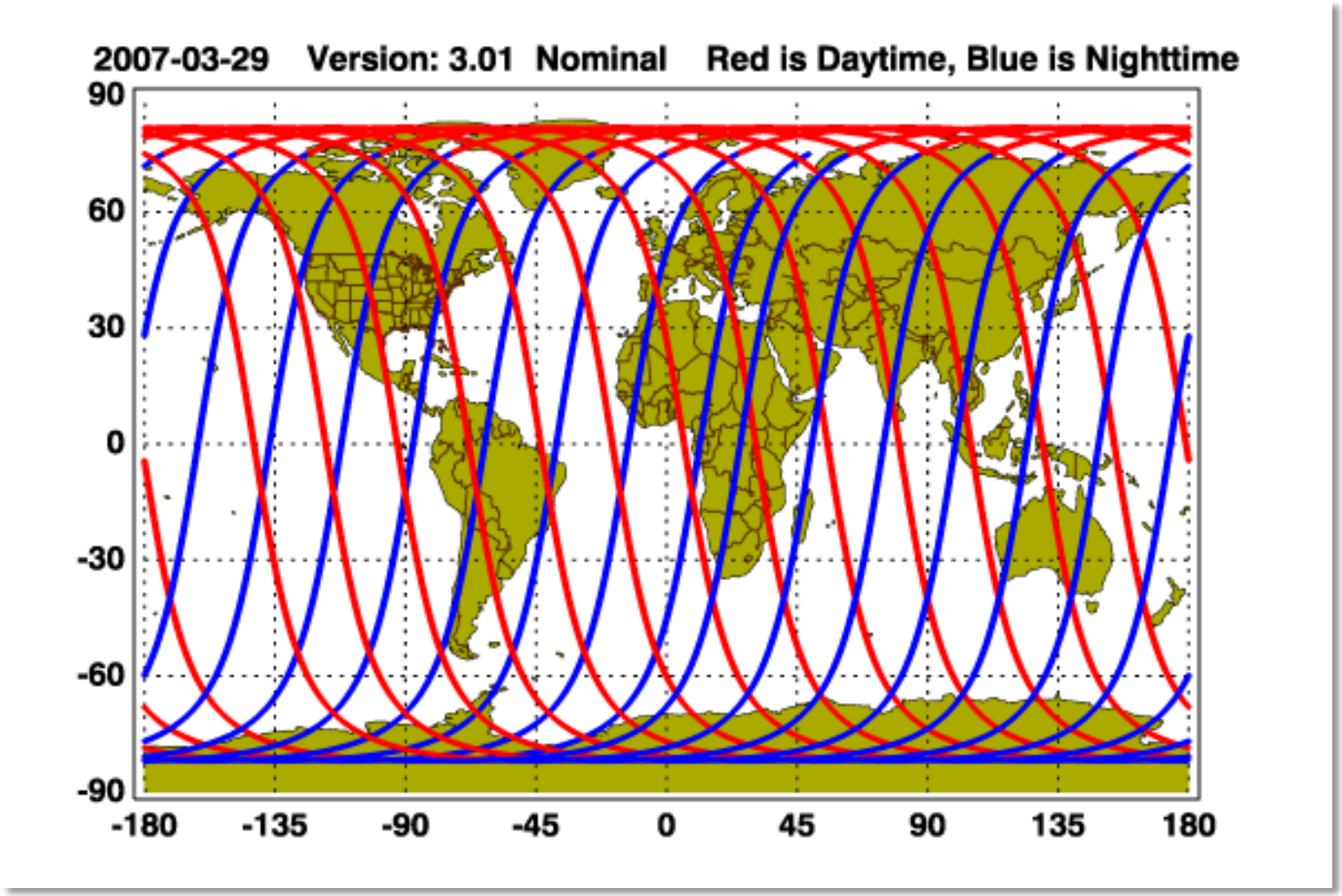
- Zero swath angle
  - Only overhead or underneath
- Fine resolution in vertical profile and time
- Depolarization (= existence of dust particles) can be detected
- Both daytime and nighttime
- Both over oceans and lands
  - Desert areas can be observed

Satellite-borne Lidar



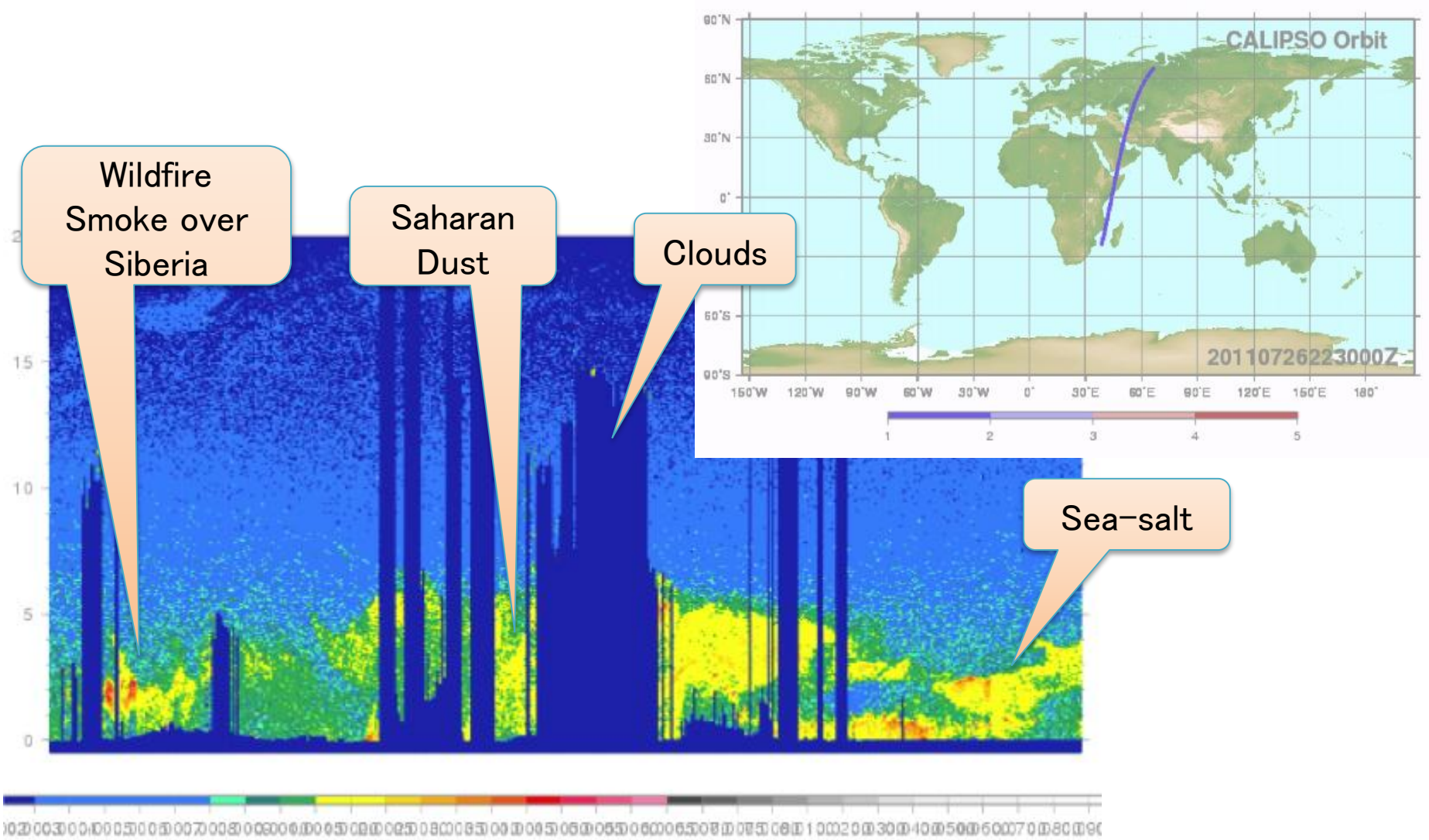
CALIPSO: aerosol lidar satellite; launched by NASA in 2006; still working in 2013

One-day CALIPSO Orbit



Horizontally sparse (about 1000 km longitudinal interval per day at mid-latitudes); zero view angle

Measured by CALIPSO



Attenuated Backscattering measured by CALIPSO

Challenging Approaches

- Aerosol data assimilation with the ensemble Kalman filter
  - Not only dust, but also sulfate aerosol
- Satellite-borne lidar observations
  - Level 1B data = depolarization ratio and attenuated backscattering coefficients at 532 and 1064 nm
- Control variables = aerosol concentrations and dust emission

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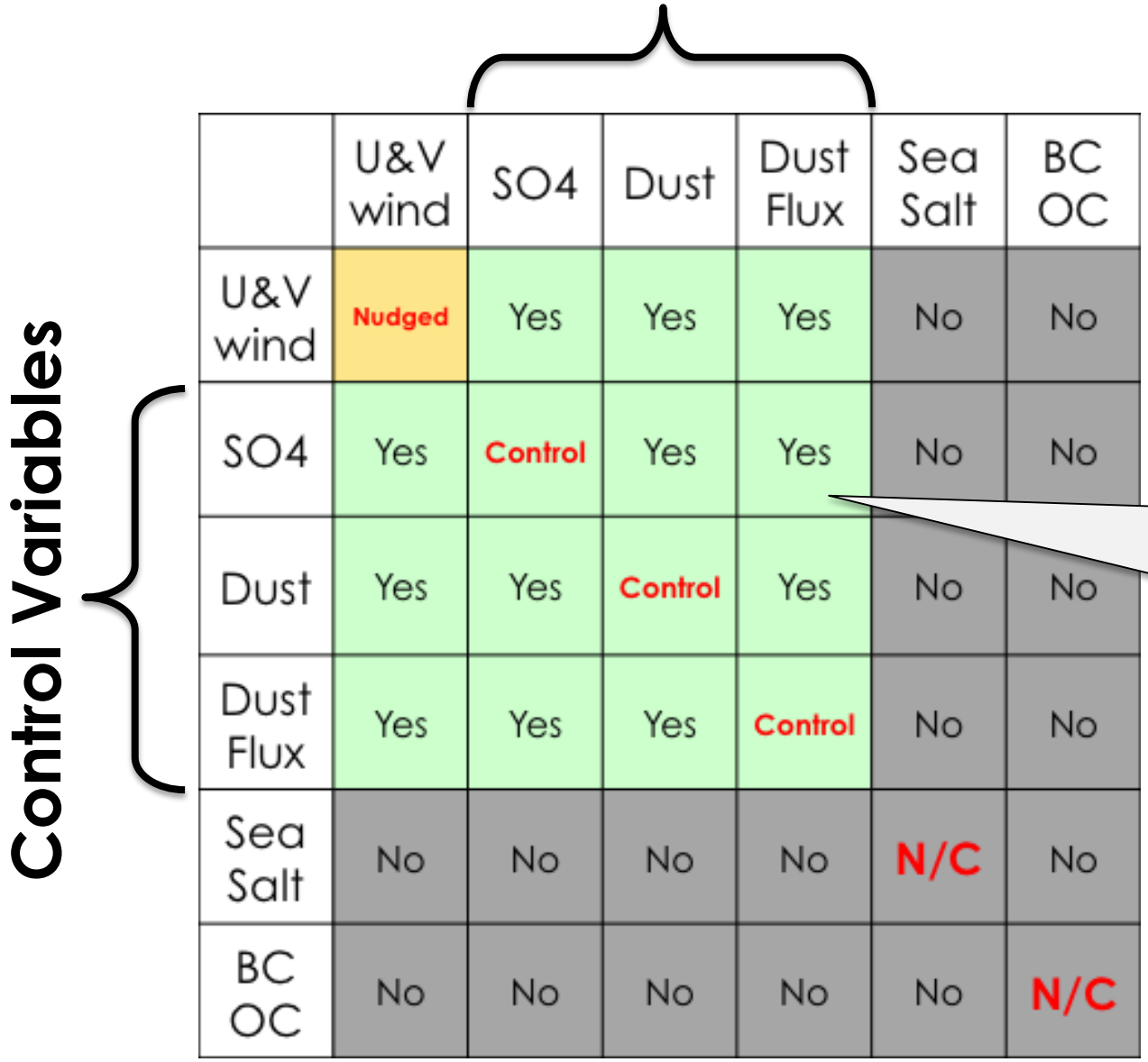
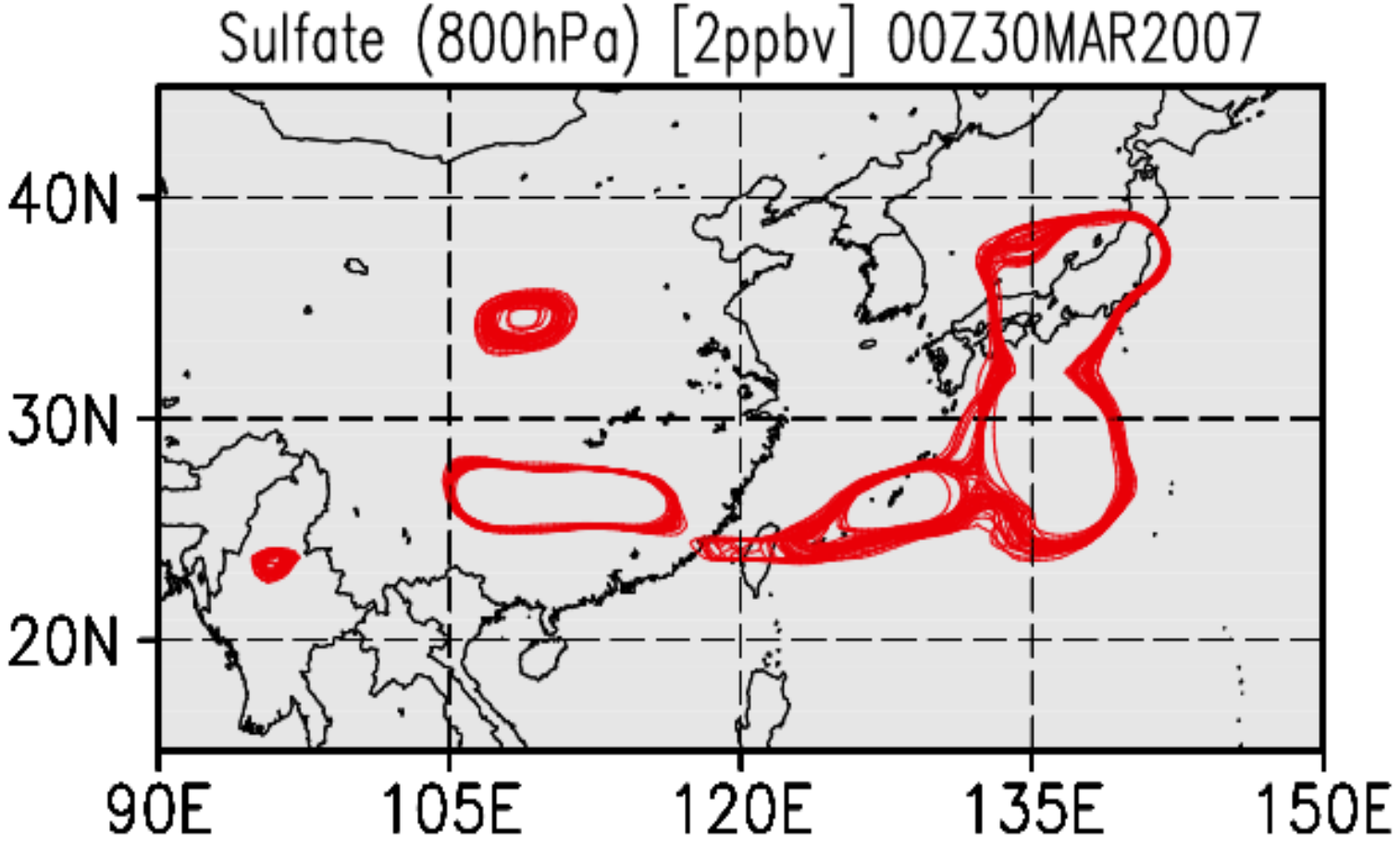
Data Assimilation with LETKF

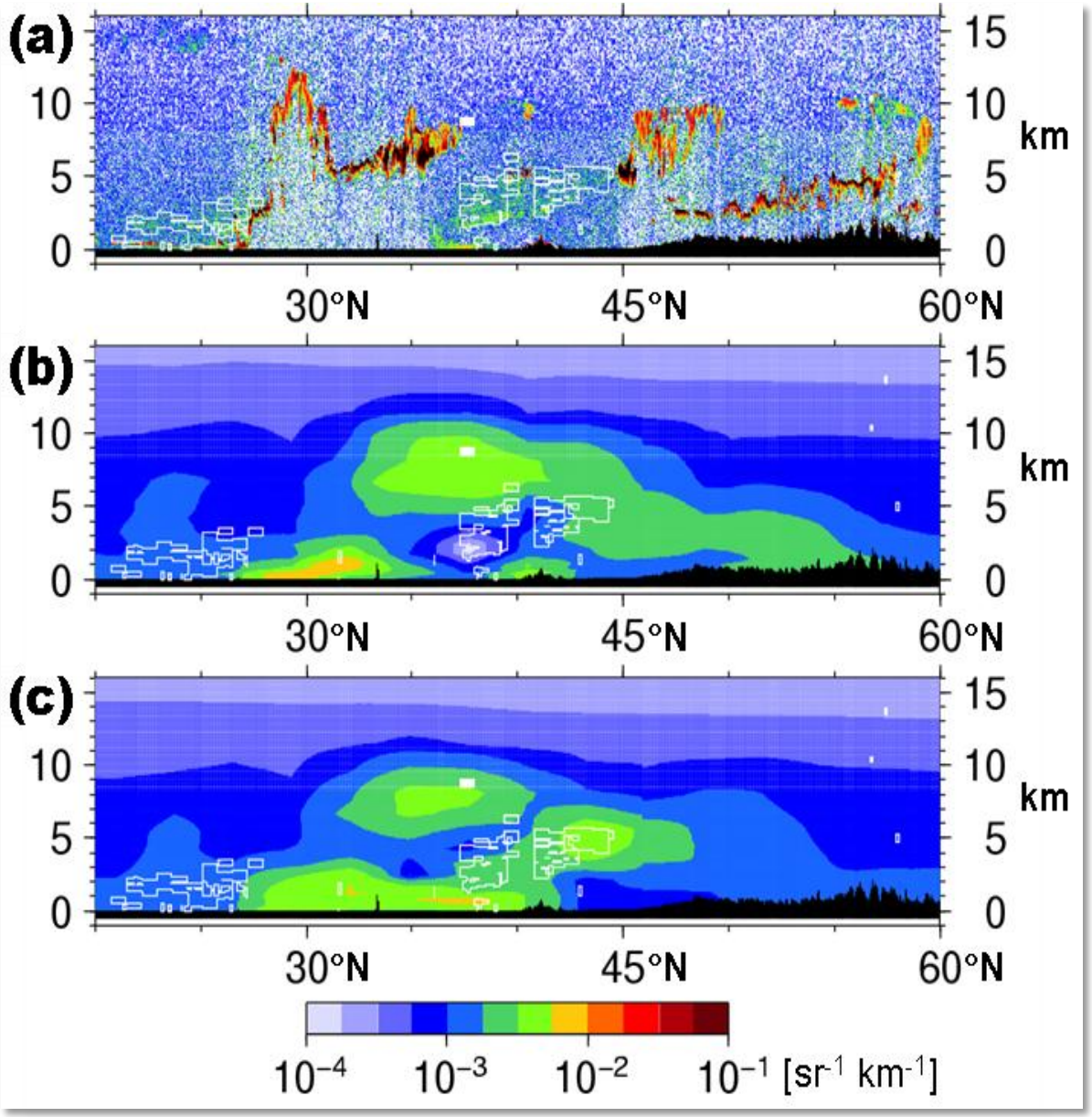


Data Assimilation with LETKF



Ensemble simulation: 32-member contour lines of 2-ppbv sulfate aerosol.

Before and After



Attenuated backscattering coeff. at 532 nm (= Observed variable);

(a) CALIPSO data;

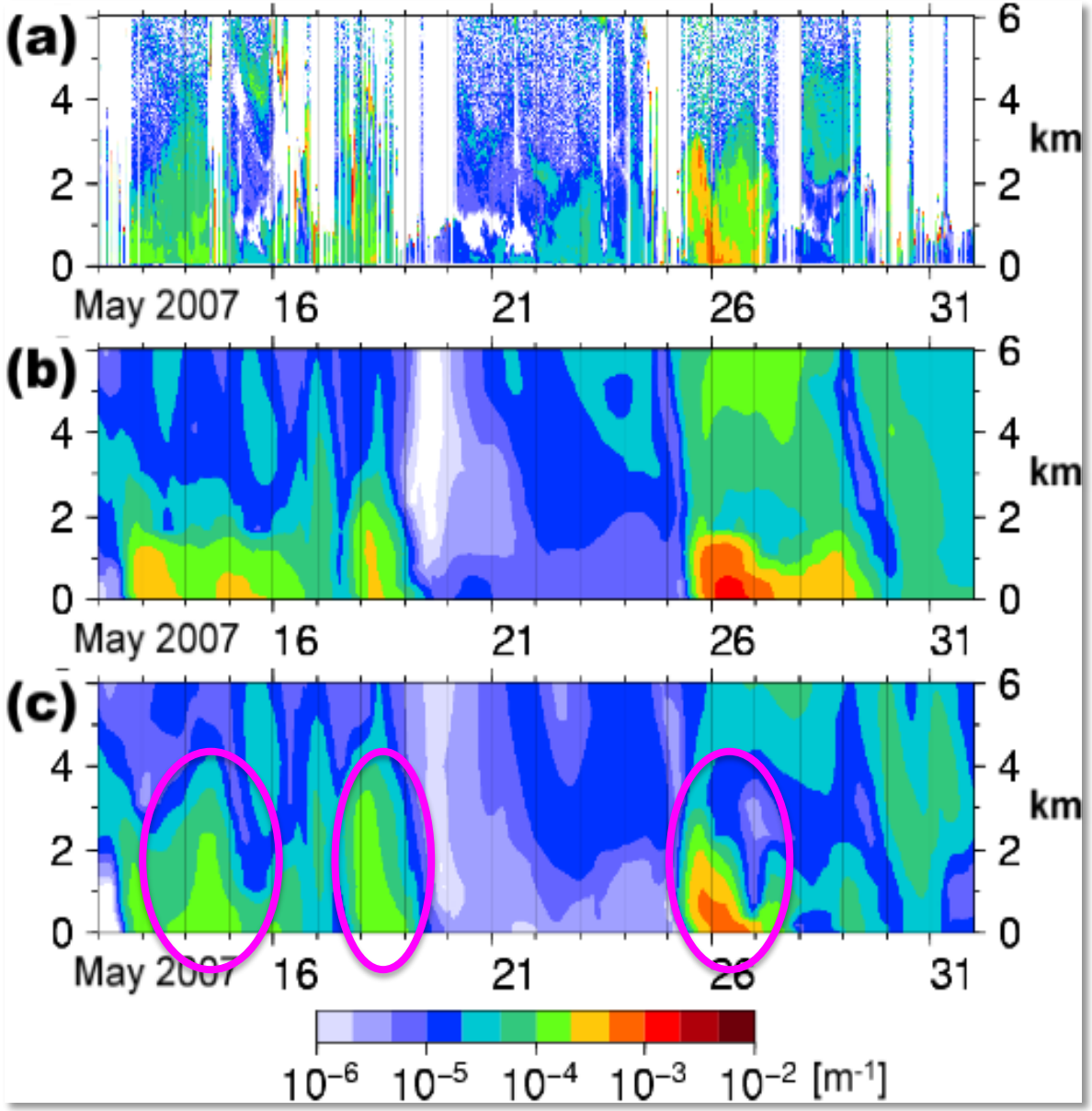
(b) model without data assimilation;

(c) model with data assimilation.

White squares indicate aerosol plumes detected.

Sekiyama et al., ACP (2010)

Independent Observations



Comparison of 532nm extinction coefficients for dust aerosol at Shimane.

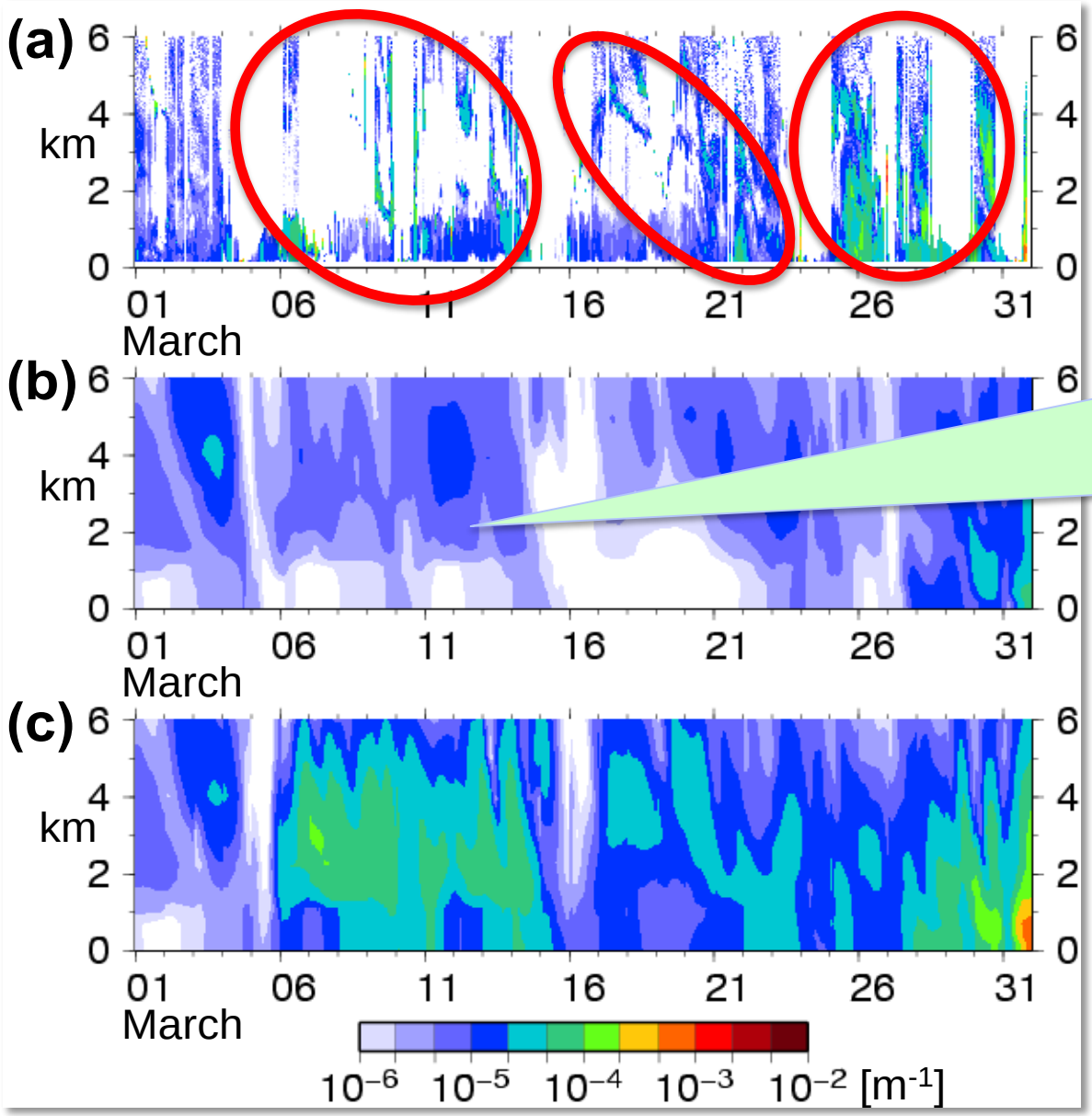
(a) Independent ground-based lidar observation;

(b) free model-run results without data assimilation;

(c) CALIPSO data assimilation results.

Sekiyama et al., ACP (2010)

Independent Observations



Comparison of 532nm extinction

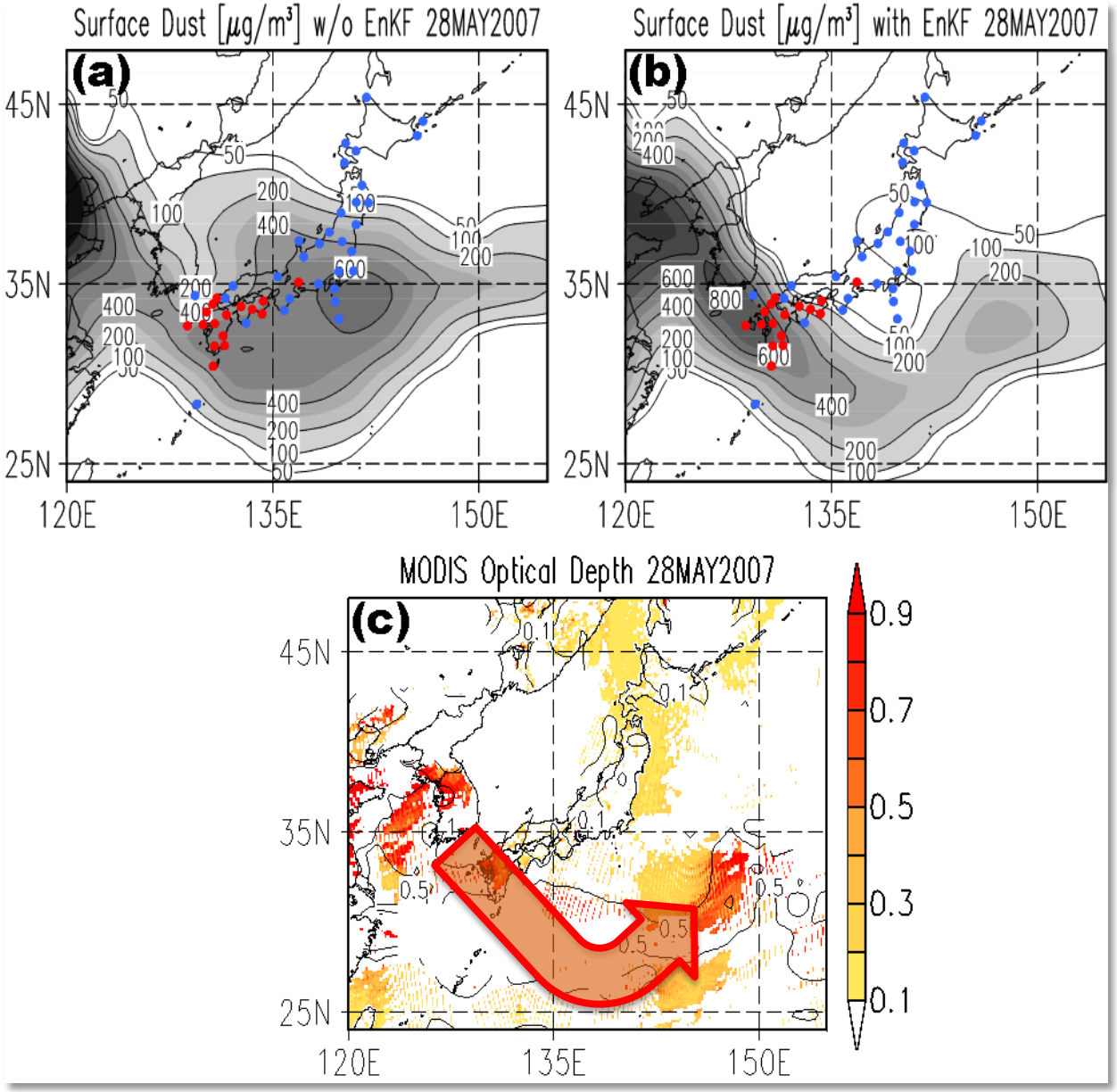
Difficult to estimate Asian dust emission in early springtime because its arid regions are often covered with snow.

(b) free model-run results without data assimilation;

(c) CALIPSO data assimilation results.

Sekiyama et al., SOLA (2011)

Independent Observations



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

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

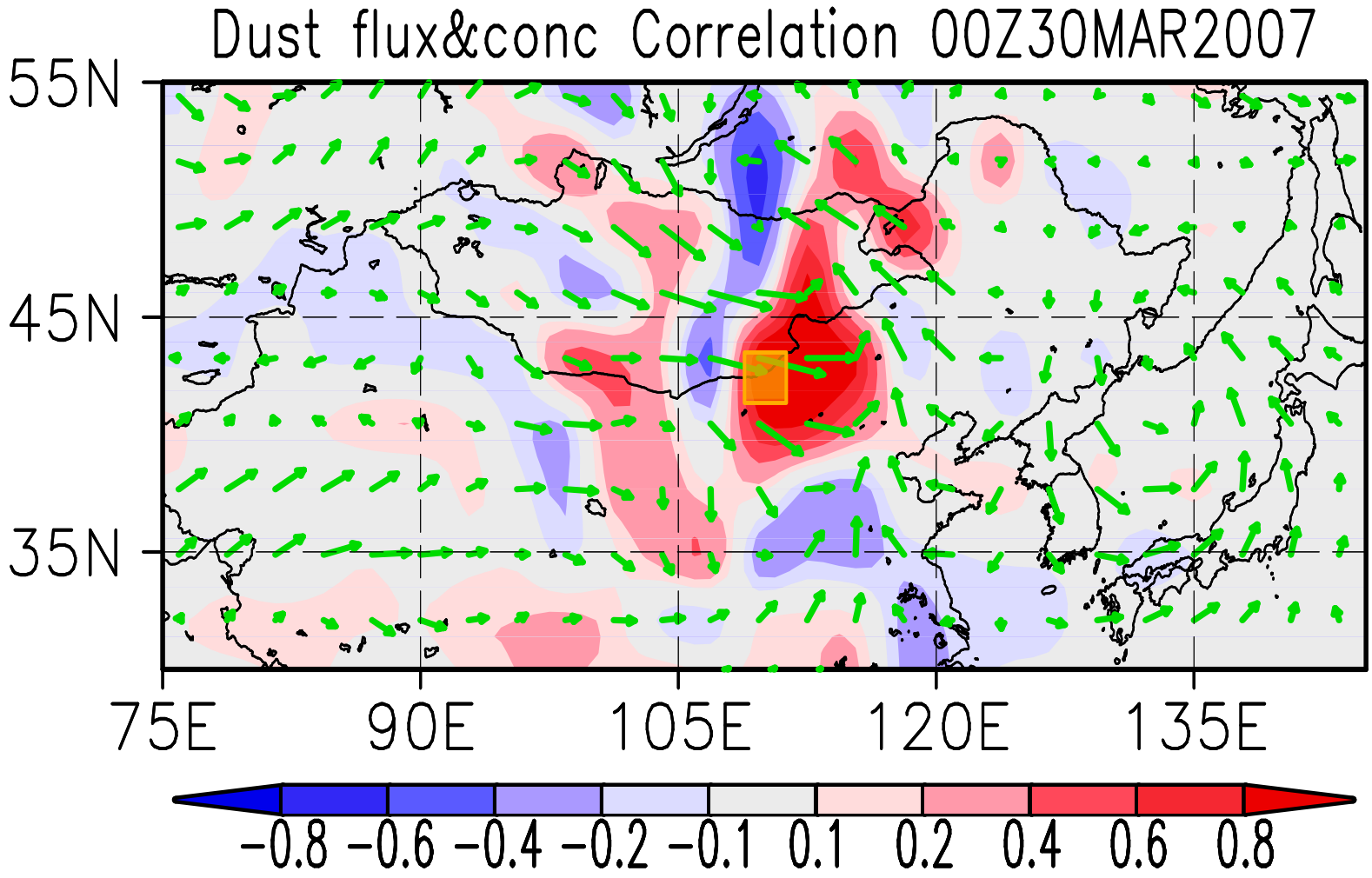
(b) CALIPSO data assimilation result.

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)

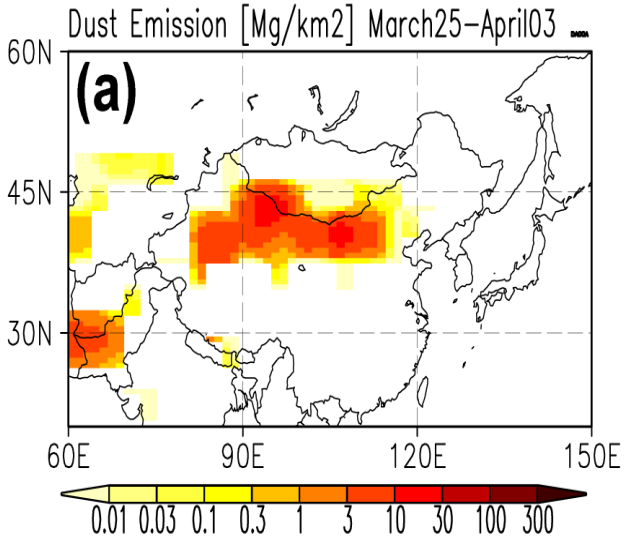
Dust Emission Estimation

Correlation between the dust emission & concentration enables inverse analysis.

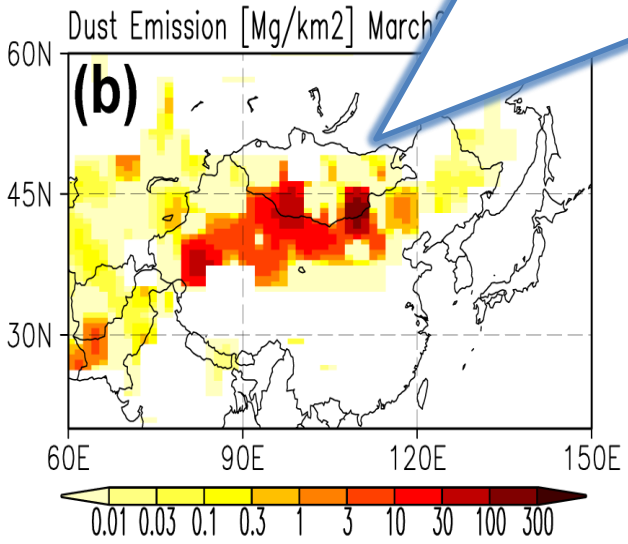


Dust Emission Estimation

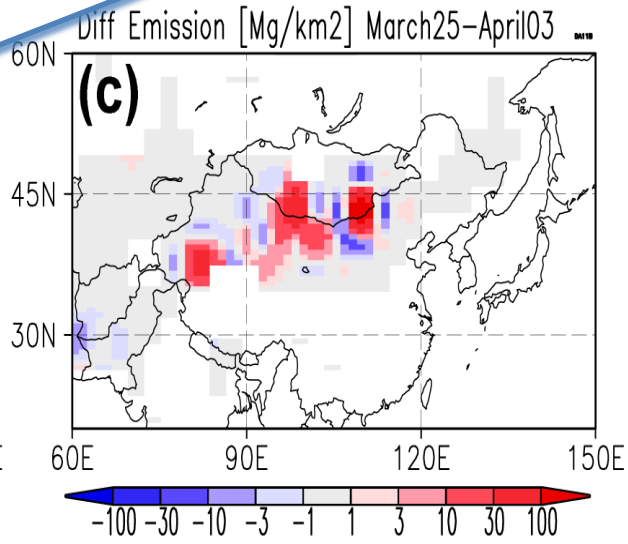
It is impossible to observe dust emission directly and extensively.



Free Model run



Assimilation Result

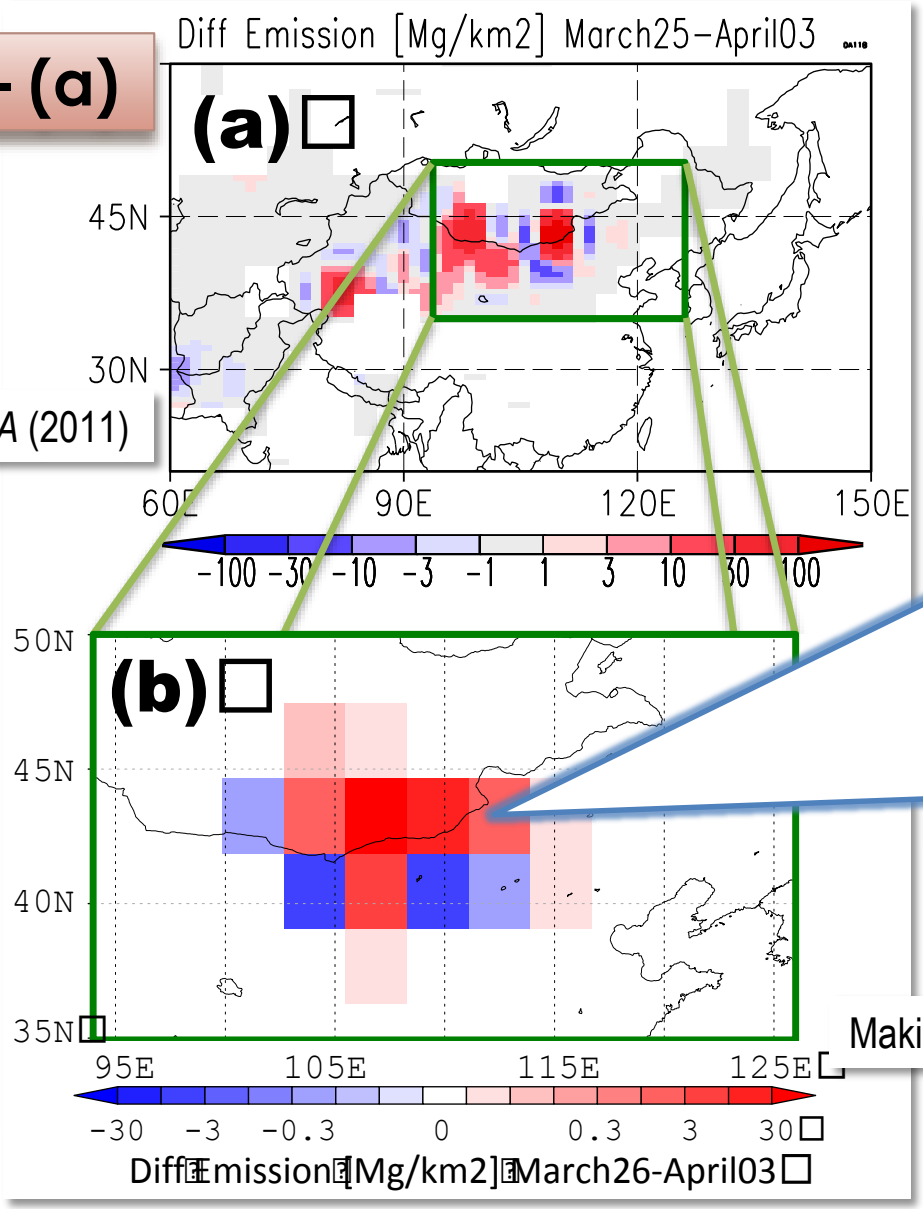


Diff = (b)−(a)

Sekiyama et al., SOLA (2011)

Dust Emission Estimation

Diff = (b) – (a)



Sekiyama et al., *SOLA* (2011)

Inversion analysis using Bayesian synthesis method

Maki et al., *SOLA* (2011)

They used the same model (MASINGAR) and different observations (surface PM_{10} in South Korea and Japan).
=> Pretty good agreement in the Gobi desert.

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Summary

- Satellite Lidar data assimilation of aerosols was successfully performed by LETKF for the first time.
  - Lidar's 2-D information was extrapolated upstream 3-dimensionally.
- Dust concentration analysis was verified by independent observations.
- Dust emission can be estimated using lidar observations.

Present and Future Work

Ongoing Experiments:

- Observation System Simulation Experiments (**OSSE**) for sulfate aerosols
- OSSE for **EarthCARE** (equipped with lidar, radar and imager; to be launched in 2015 by JAXA and ESA)

Future Plan:

- JMA to start operational aerosol forecasting in 2015 with EarthCARE and LETKF