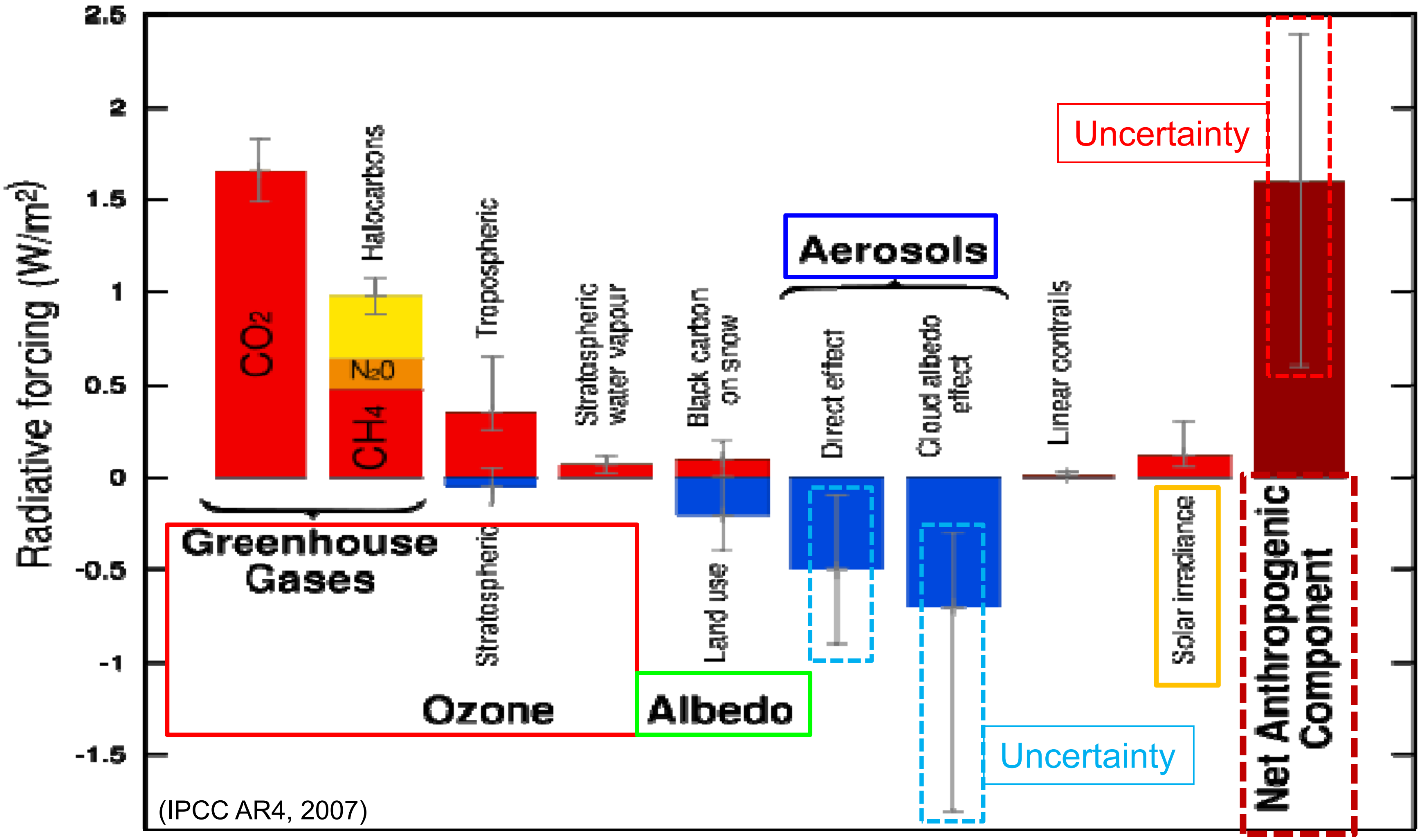
Remote Sensing of Aerosol Types and the Potential Weight of Mixing components

Tang-Huang Lin, N. Christina Hsu (NASA/GSFC),
George Lin (NCU)
Center for Space and Remote Sensing Research
National Central University, Taiwan

http://ersl.csrsr.ncu.edu.tw/

Radiative Forcing Components



Radiative Forcing Components

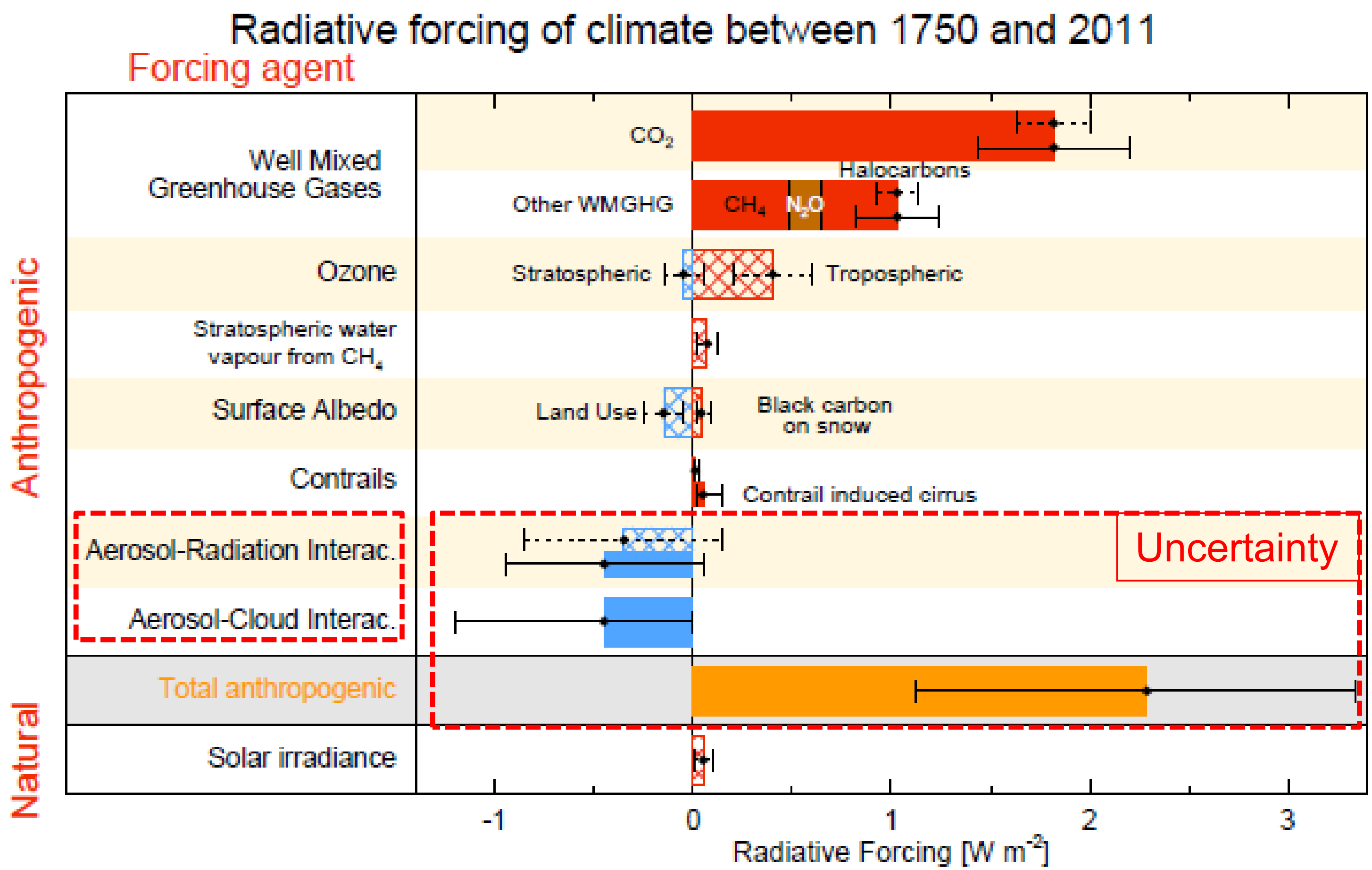
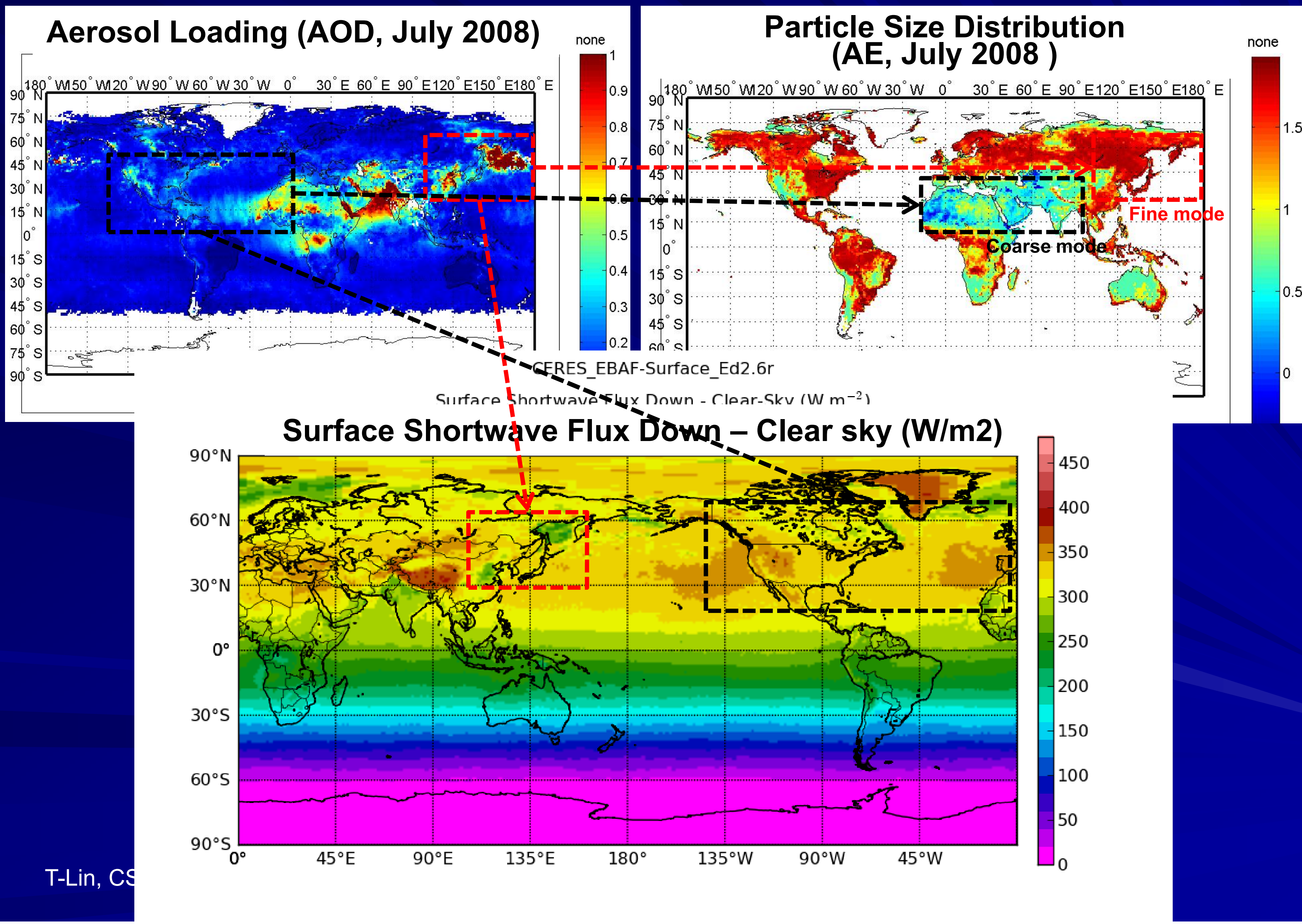


Figure 8.15: Bar chart for RF (hatched) and ERF (solid) for the period 1750–2011, where the total ERF is derived from Figure 8.16. Uncertainties (5–95% confidence range) are given for RF (dotted lines) and ERF (solid lines).

Factor of Aerosol Uncertainty

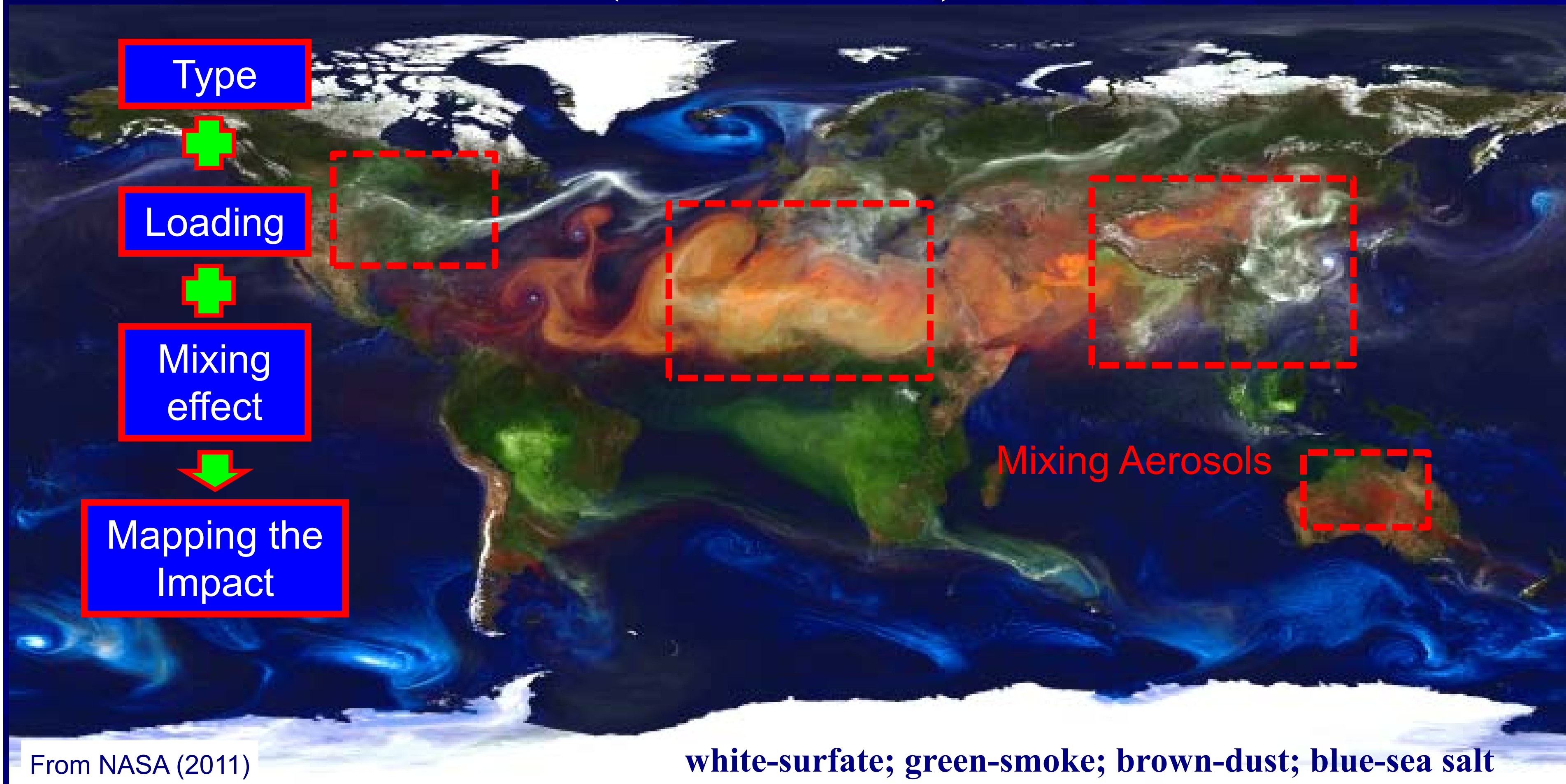
- Complex components (size, shape, material, …) – Aerosol type
- Aerosol mixtures – Mixing effect
- Highly variance in the spatiotemporal distribution – Efficient observation/monitor (Incomprehensive observation)

➢ Effect of Aerosol Types on Radiative forcing – Remote sensing



T-Lin, CS

Spatial Distribution of Aerosols (Simulated)



Focal Points

- Discrimination of aerosol type – mineral dust, smoke particles and man-made pollutant
- Mixing effect – effect of black carbon (soot) on dust property retrievals from satellite observations
- Mixing weight estimation - Application to satellite data (MODIS associated with AERONET data)

◆ Discrimination of aerosol type

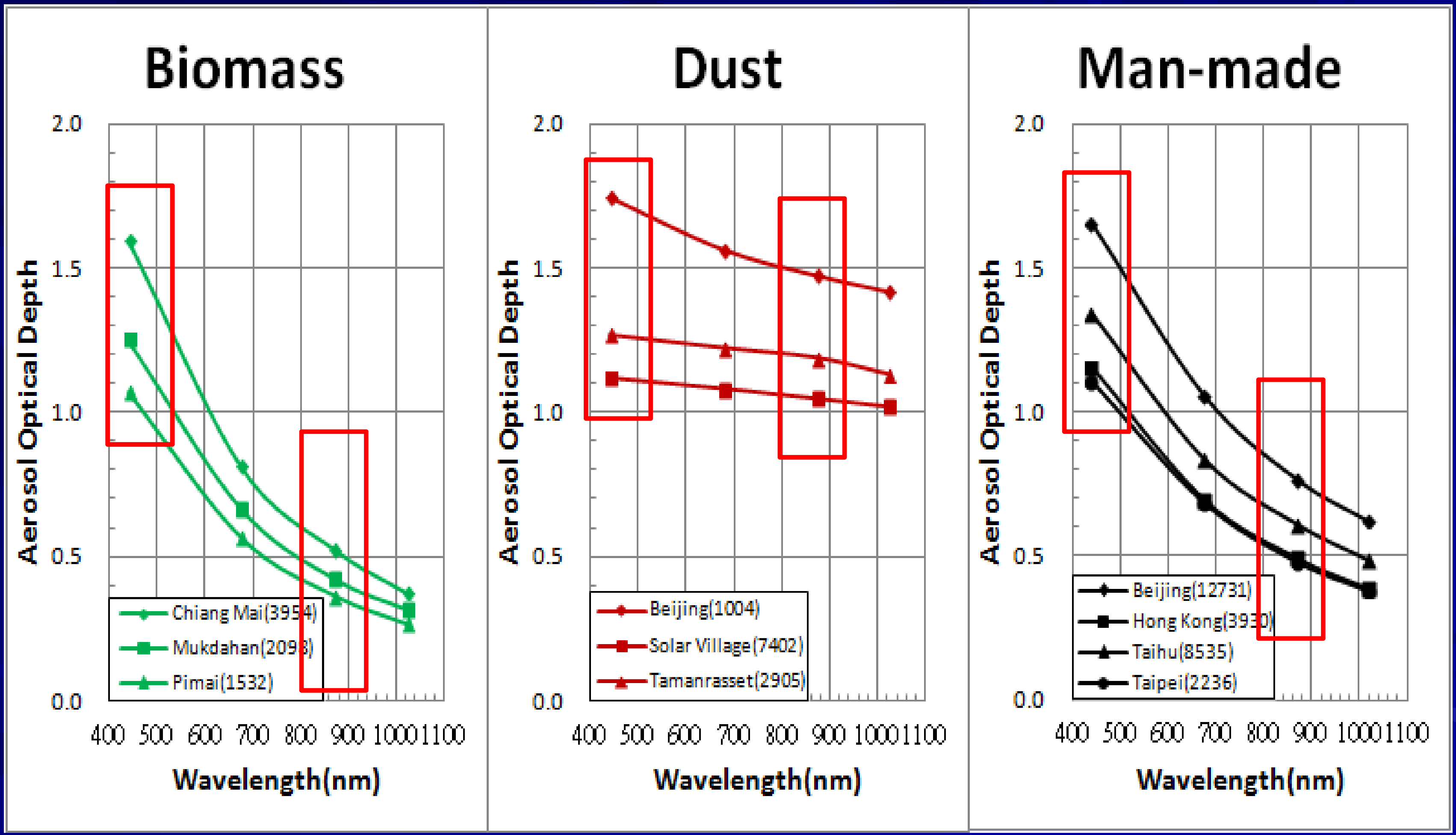
Aerosol type from ground-based and satellite

AERONET (Surface)	Dust Particles	Biomass Burning	Man-made Pollutants
Ångström exponent (α) 440_675nm **(Particle Size)**	**0.066 ± 0.055 (Coarse)**	**1.499 ± 0.096 (Fine mode)**	**1.105 ± 0.269 (Fine mode)**
Single scattering albedo (SSA) 675nm **(Radiative parameter)**	**0.958 ± 0.002 (Scattering)**	**0.903 ± 0.024 (Absorption)**	**0.940 ± 0.031 (Absorption/Scattering)**

MODIS (Satellite)	Dust Particles	Biomass Burning	Man-made Pollutants
Ångström exponent (α) 440_675nm	**0.523±0.1833**	**1.3395±0.286**	**1.158±0.492**
Single scattering albedo (SSA) 675nm	**0.9311±0.0286**	**No information**	**No information**

◆ Discrimination of aerosol type

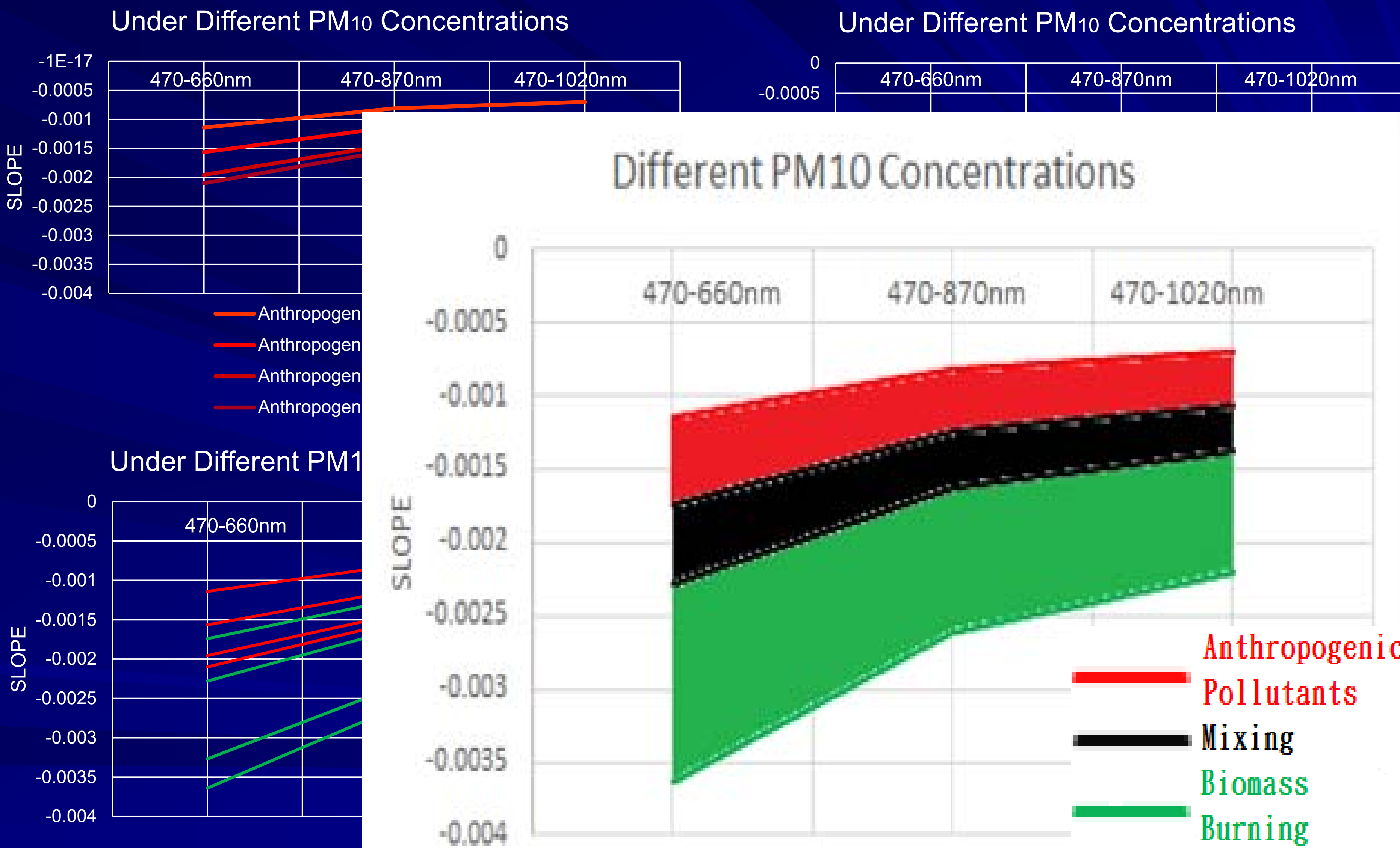
➢ **AOD along with wavelength from AERONET sites**



Relationship between AOD and PM10

Dust	Relationship	Correlation Coefficient(R)
Sano et al. (2010) 675nm, PM2.5	$PM_{2.5} = 52.8 * AOD_{675nm} + 9.68$	0.61
Man-made	**Relationship**	**Correlation Coefficient(R)**
Sano et al. (2010) 675nm, PM2.5	$PM_{2.5} = 62.4 * AOD_{675nm} + 12.4$	0.60
Our Study 675nm, PM2.5	$PM_{2.5} = 51.39 * AOD_{675nm} + 11.304$ $PM_{2.5} = 14.38 * \ln(AOD_{675nm}) + 47.38$	0.55 0.56
Our Study 440nm, PM2.5	$PM_{2.5} = 33.54 * AOD_{440nm} + 9.41$ $PM_{2.5} = 14.19 * \ln(AOD_{440nm}) + 39.09$	0.57 0.57
Our Study 675nm, PM10	$PM_{10} = 70.02 * AOD_{675nm} + 36.53$ $PM_{10} = 26.36 * \ln(AOD_{675nm}) + 94.42$	0.59 0.64
Our Study 440nm, PM10	$PM_{10} = 44.89 * AOD_{440nm} + 34$ $PM_{10} = 28.02 * \ln(AOD_{440nm}) + 80.66$	0.61 0.66
Biomass	**Relationship**	**Correlation Coefficient(R)**
Our Study 675nm, PM10	$PM_{10} = 98.26 * AOD_{675nm} + 15.36$	0.73
Our Study 440nm, PM10	$PM_{10} = 53.24 * AOD_{440nm} + 15.99$	0.78

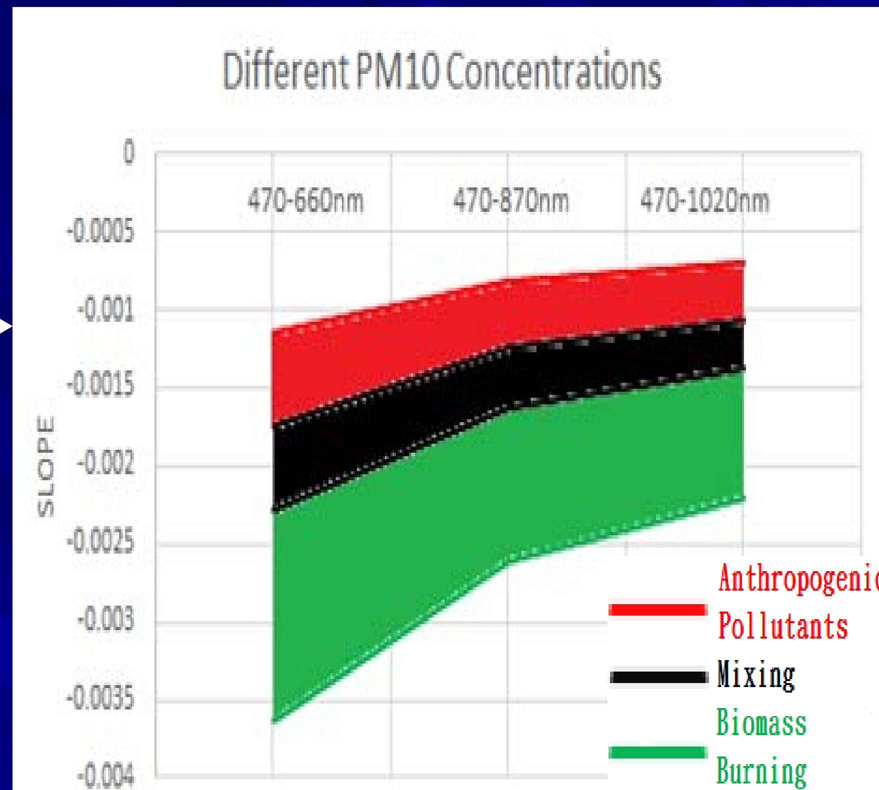
The criteria of Aerosol Type Discrimination



Flow chart of aerosol type identification

AODs (Aerosol optical depth) → AE < 0.8

No →



Yes ↓

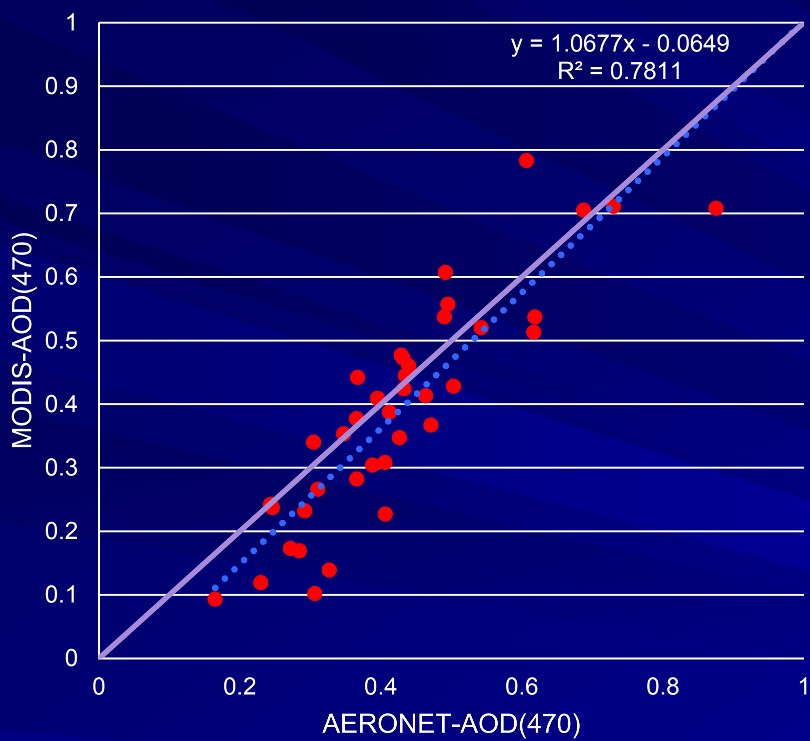
Dust

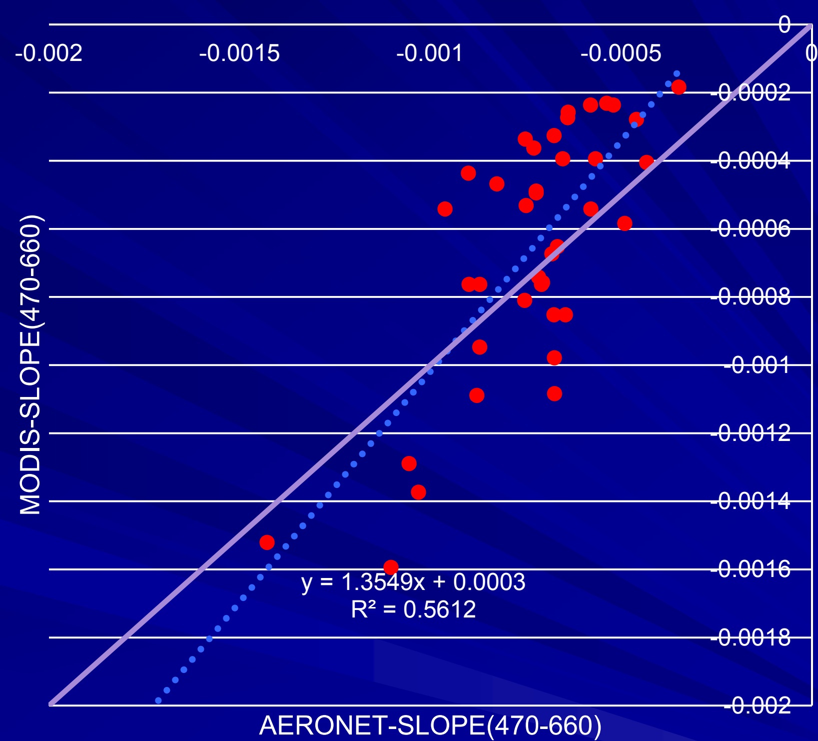
Biomass

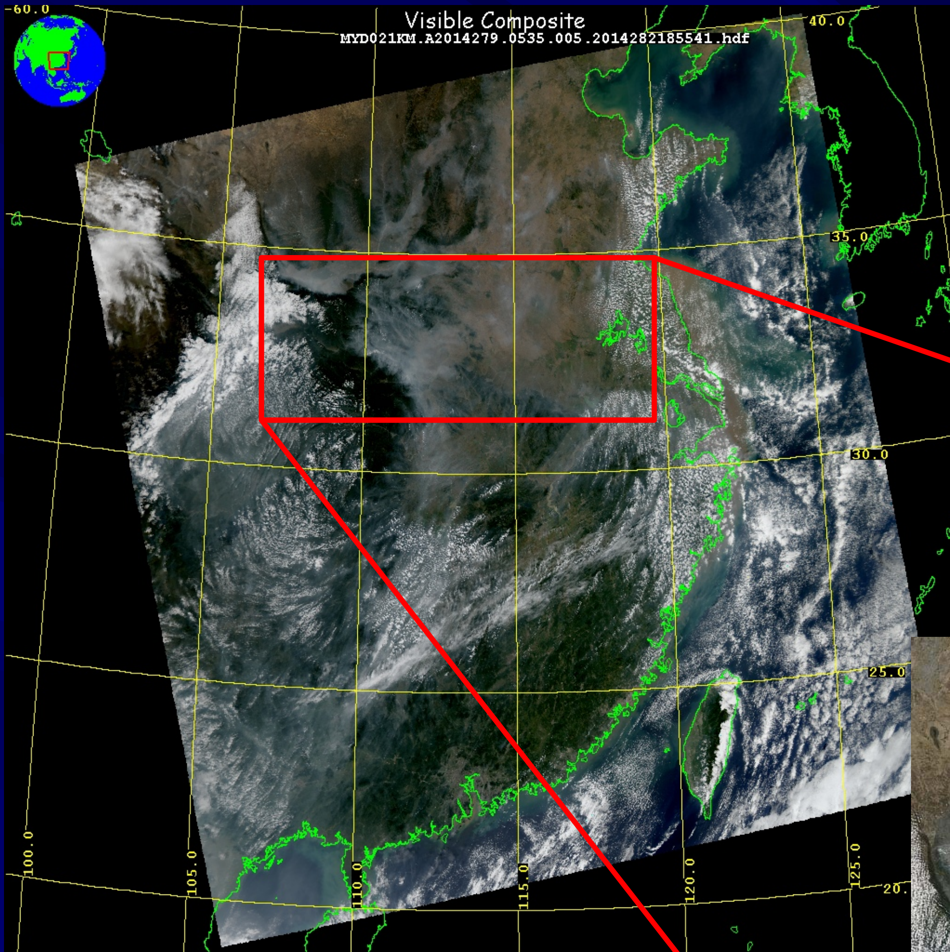
Man-made

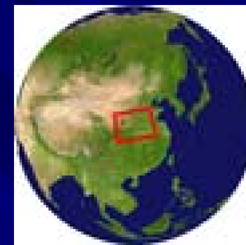
Others

Systemic Calibration of AOD between MODIS and AERONET

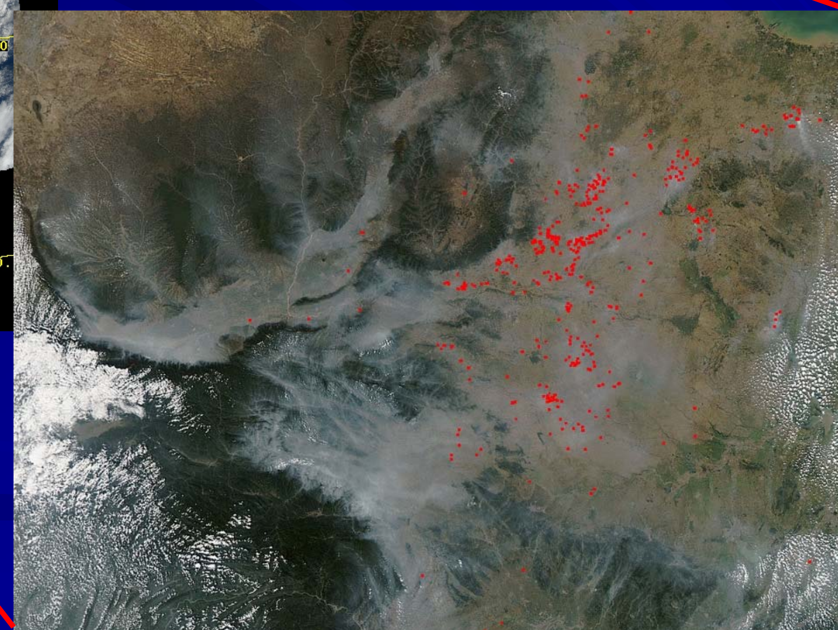


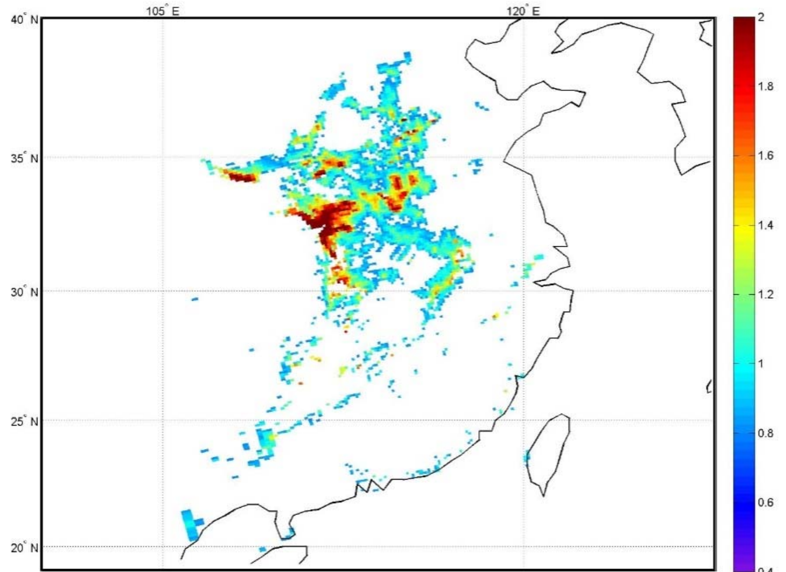






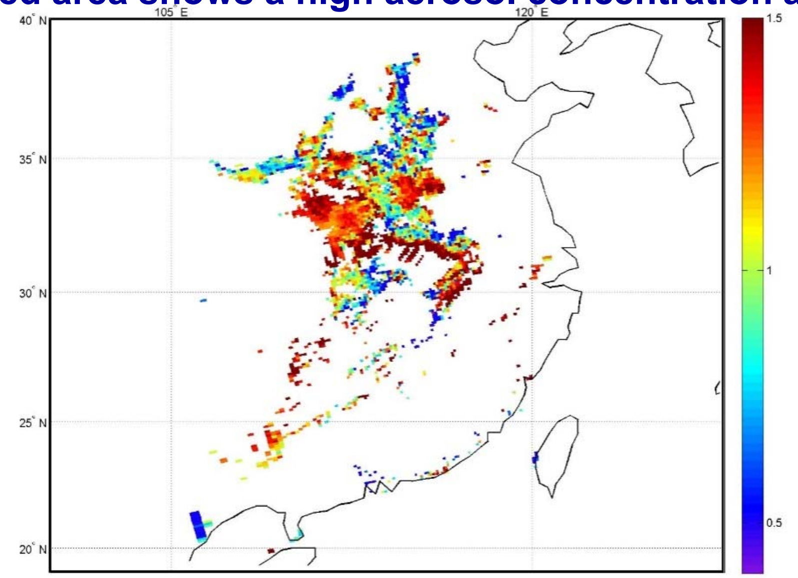
Aqua/MODIS
2014/279
2014/10/06
05:35 UTC



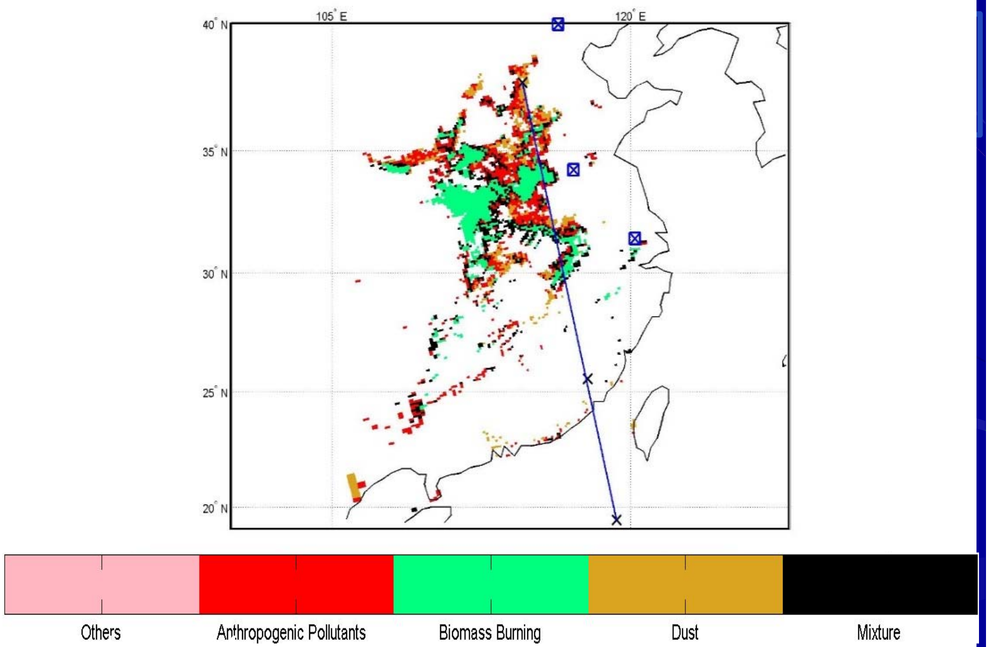


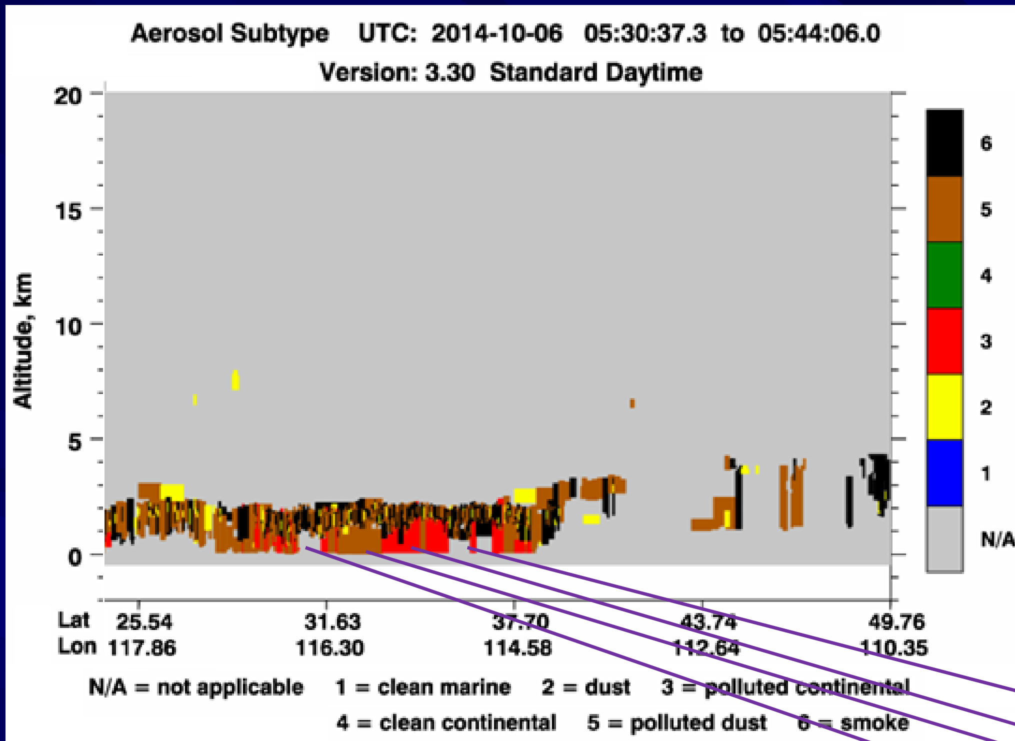
MODIS/Aqua, 2014/10/06 aerosol optical depth(AOD). The red area shows a high aerosol concentration area.

AERONET	Smoke Pollutants	Background Particles
AOD (500nm)	0.984 ± 0.221	0.138 ± 0.022
AE (α) (440_675nm)	1.449 ± 0.096	1.489 ± 0.320
SSA (675nm)	0.903 ± 0.024	0.839 ± 0.022



MODIS/Aqua, 2014/10/06 Angstrom Exponent(AE). Bright area shows a fine particle aerosol area.





Anthropogenic pollution:

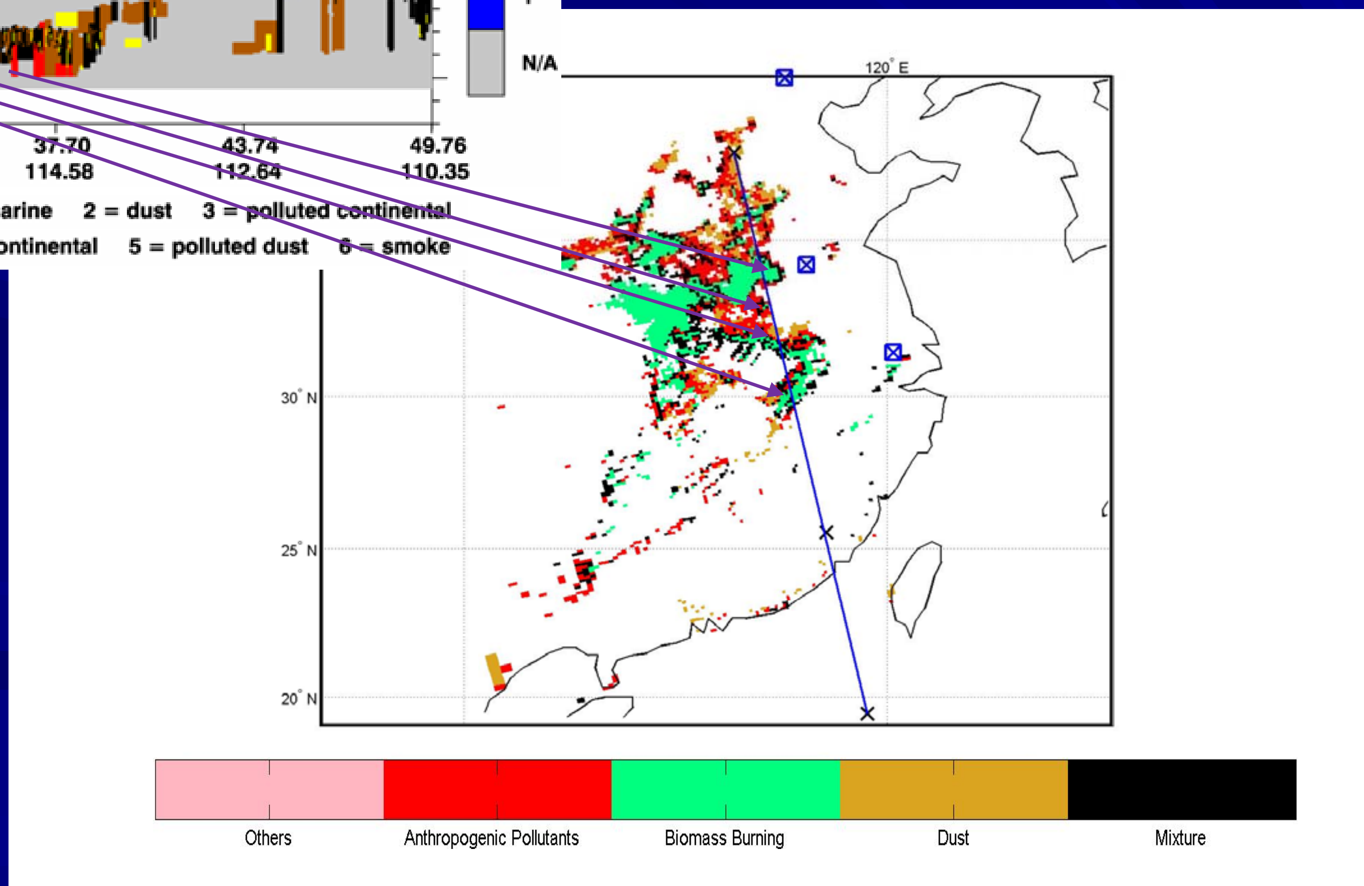
Mean AOD:0.96±0.12

Mean AE:0.94±0.21

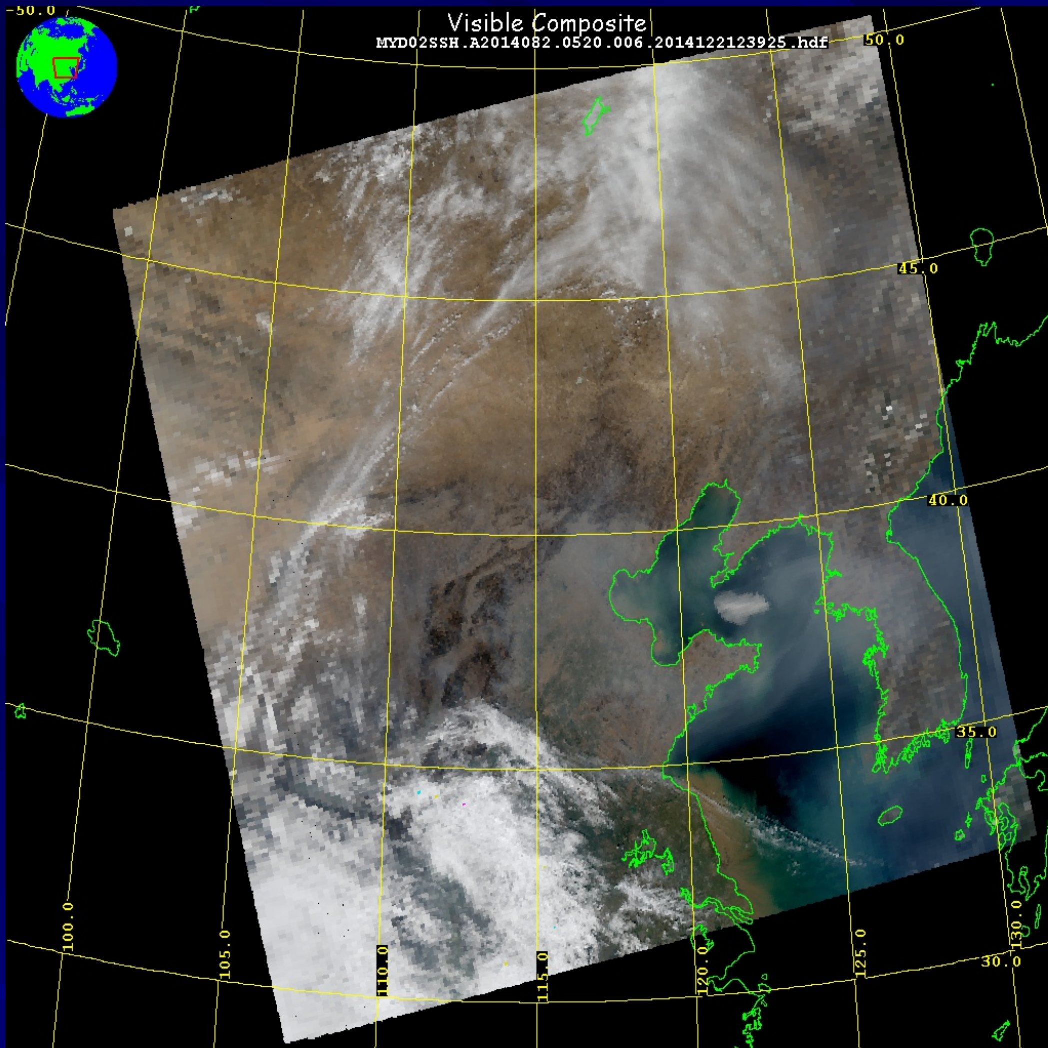
Biomass Burning:

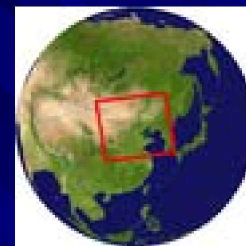
Mean AOD:1.47±0.36

Mean AE:1.32±0.15

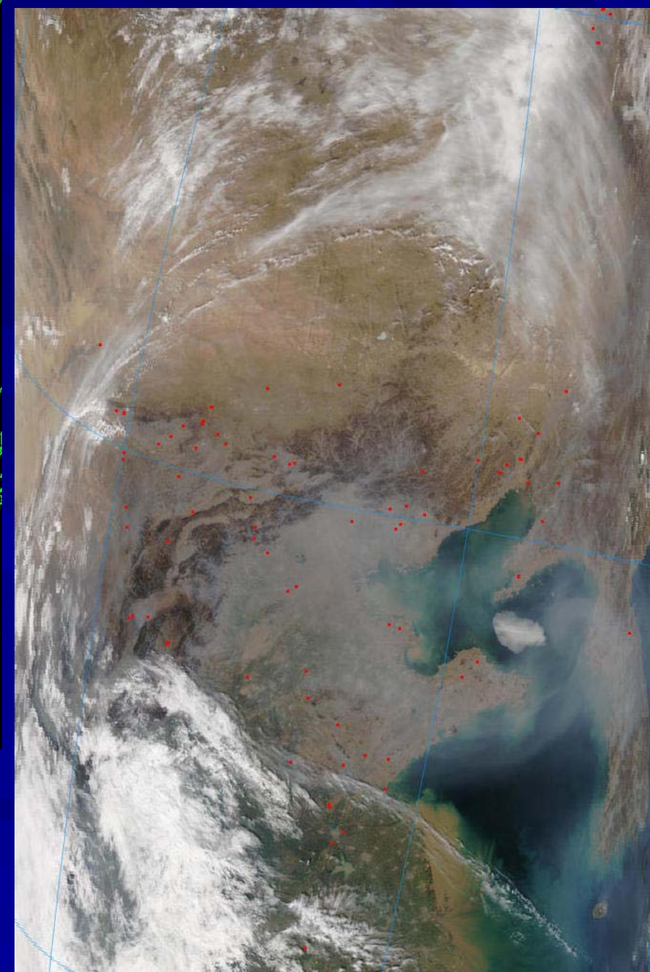


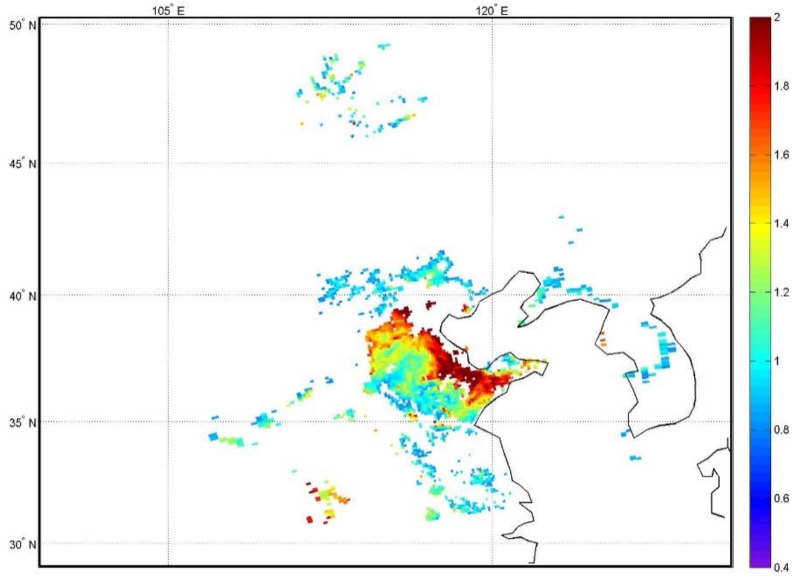
2014.12.08

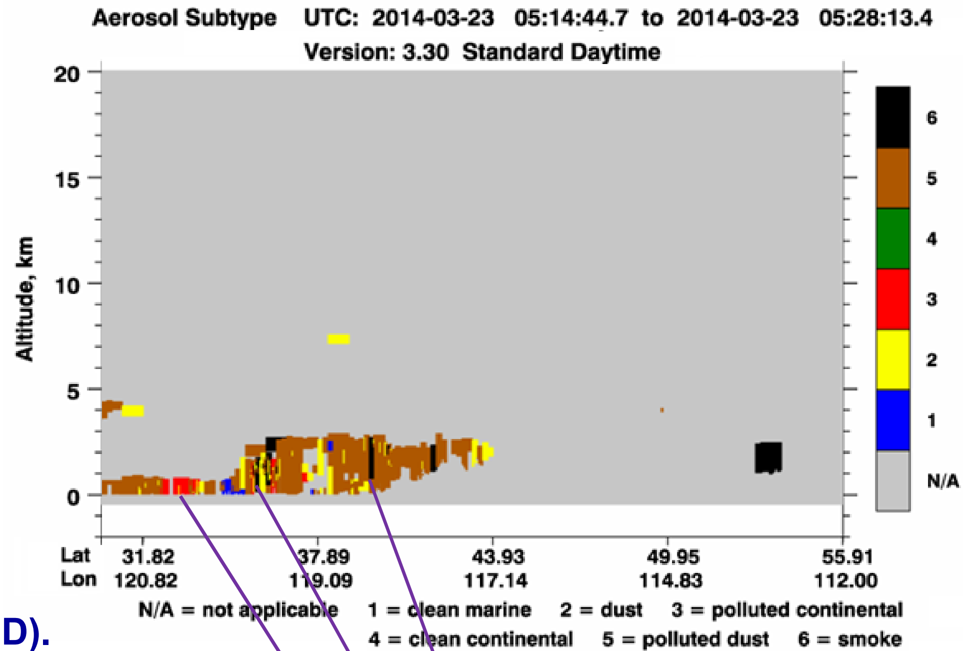




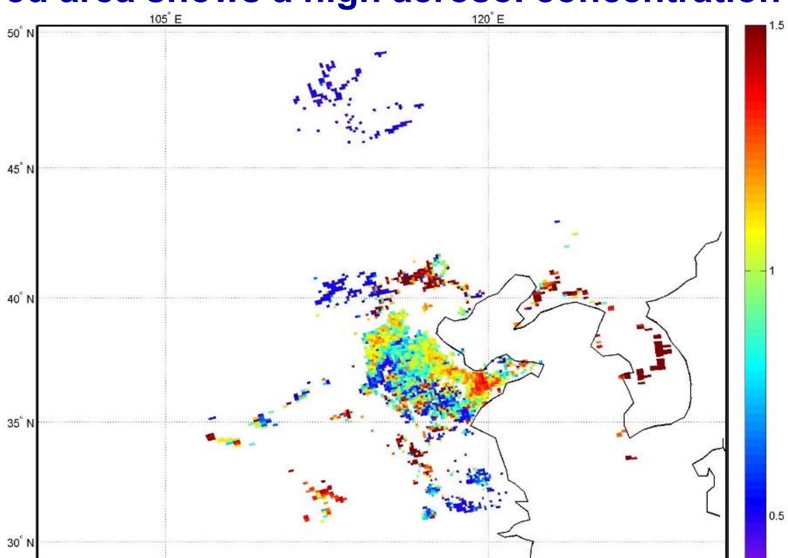
Aqua/MODIS
2014/082
2014/03/23
05:20 UTC

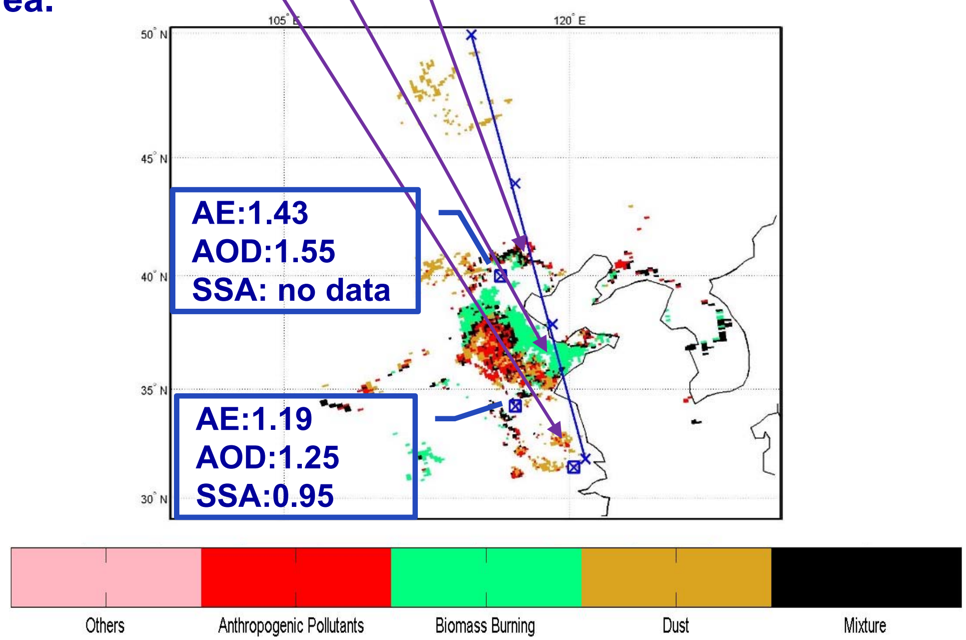






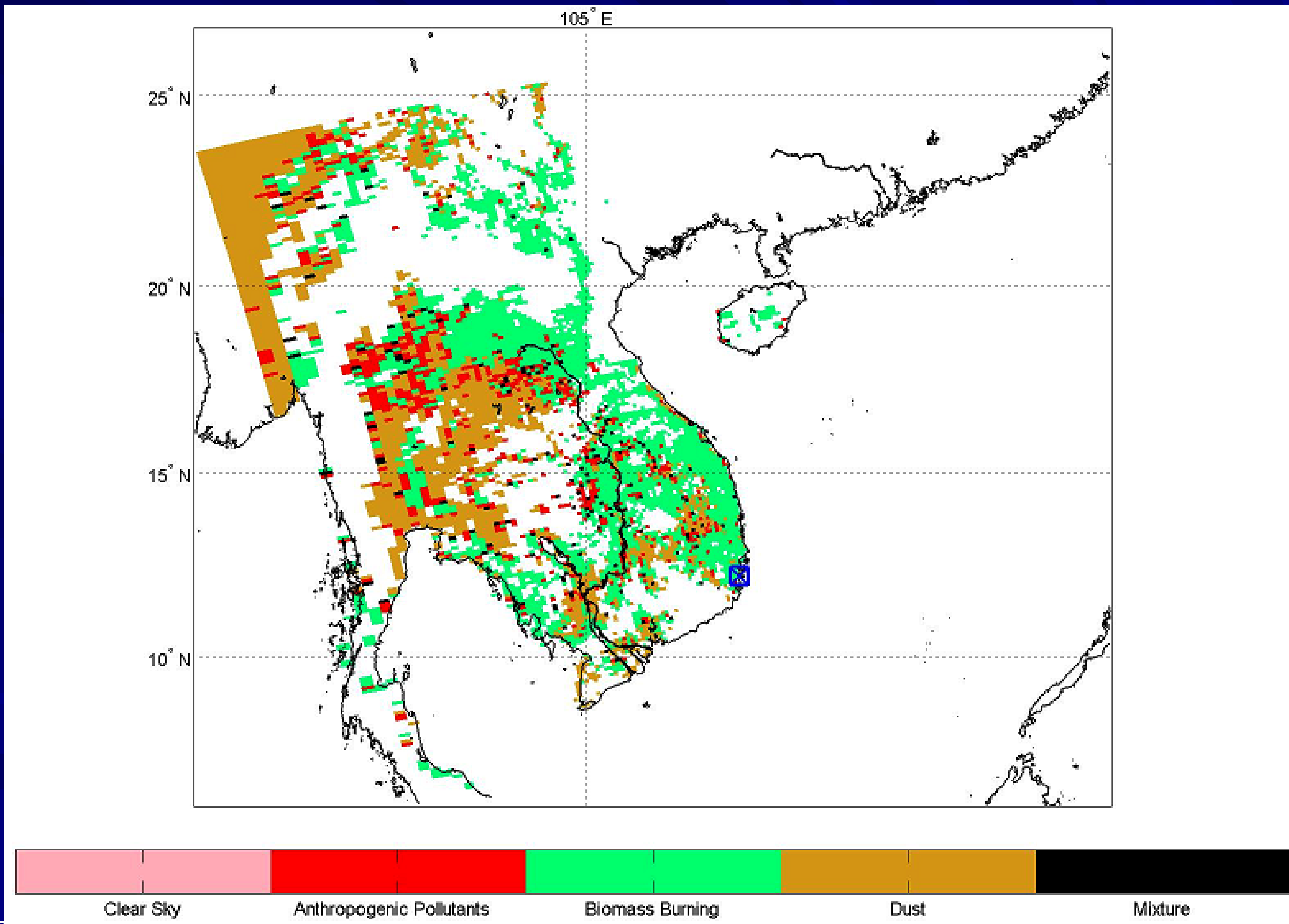
MODIS/Aqua, 2014/03/23 aerosol optical depth(AOD).
The red area shows a high aerosol concentration area.





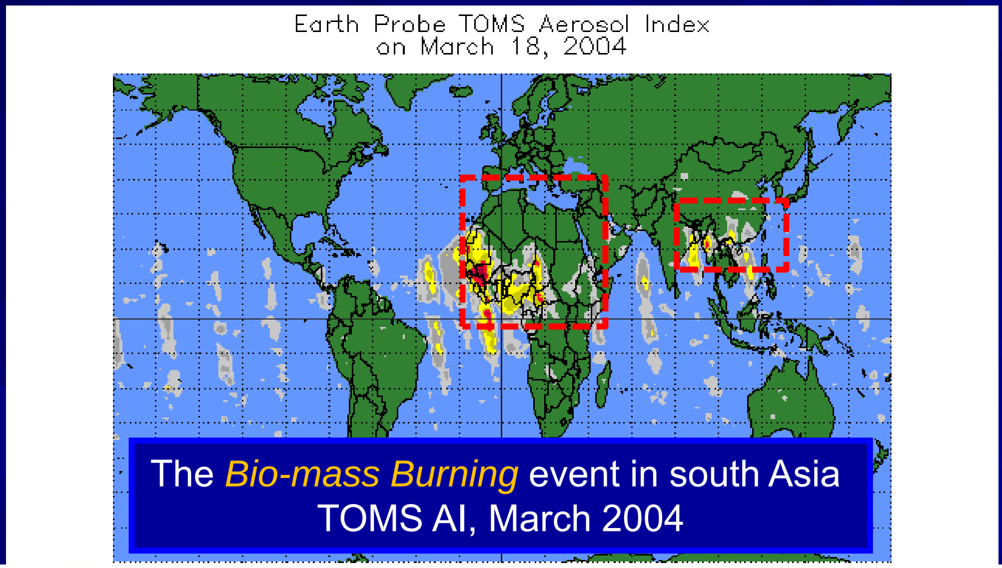
MODIS/Aqua, 2014/03/23 Angstrom Exponent(AE).
Bright area shows a fine particle aerosol area.

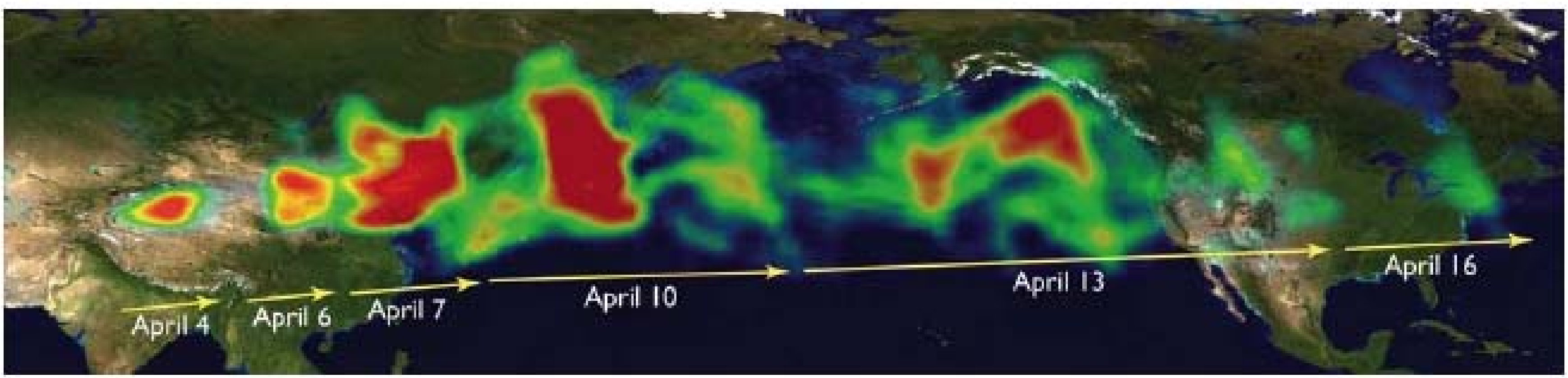
Spatial Distribution of Aerosol Types, Feb. 02, 2014



◆ Effect of Aerosol Mixing

- Asia/Africa are the major contributors to global mineral dusts and black carbon (the main component of soot)

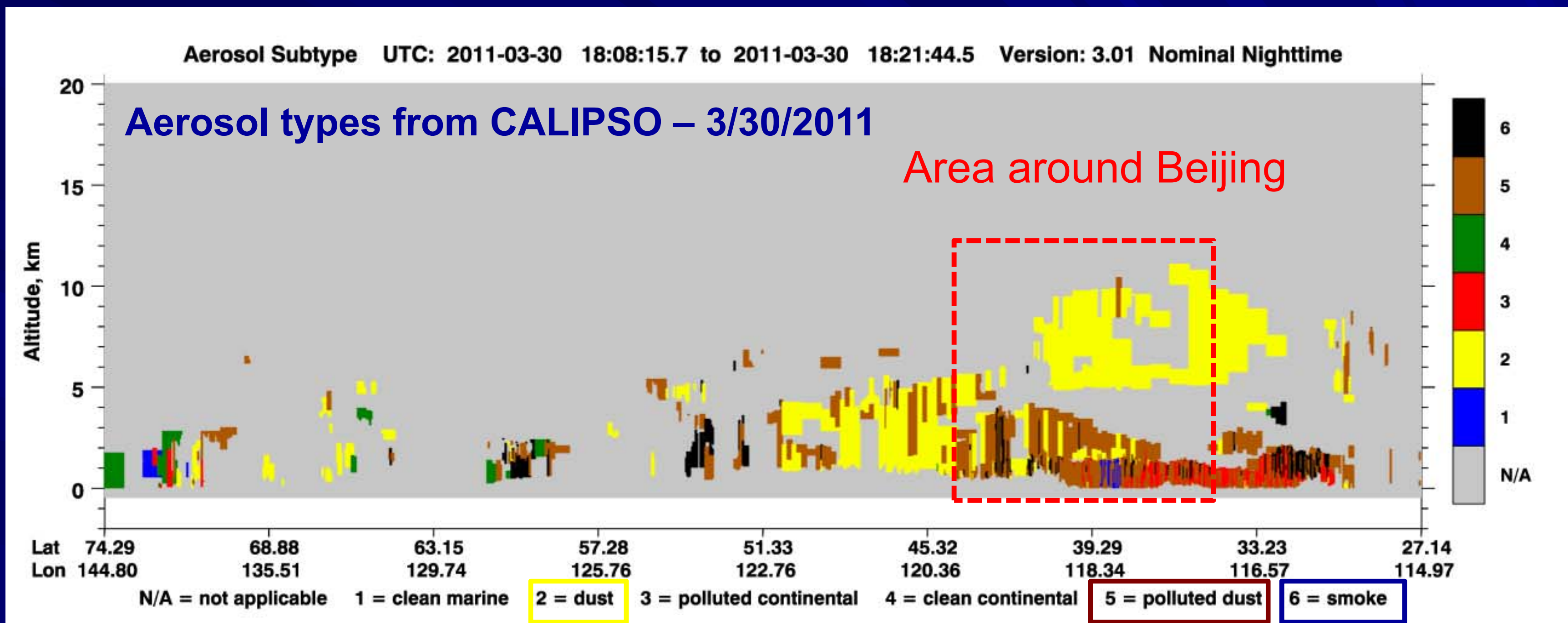


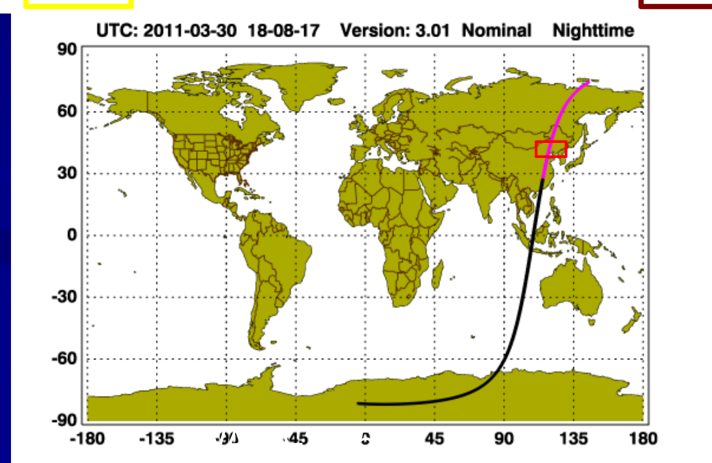


(Hsu et al., 2006)

Fig. 1. Time series of TOMS AI composite in April 2001 showing the long-range transport of Asian dust across the Pacific reaching as far as the east coast of the U.S.

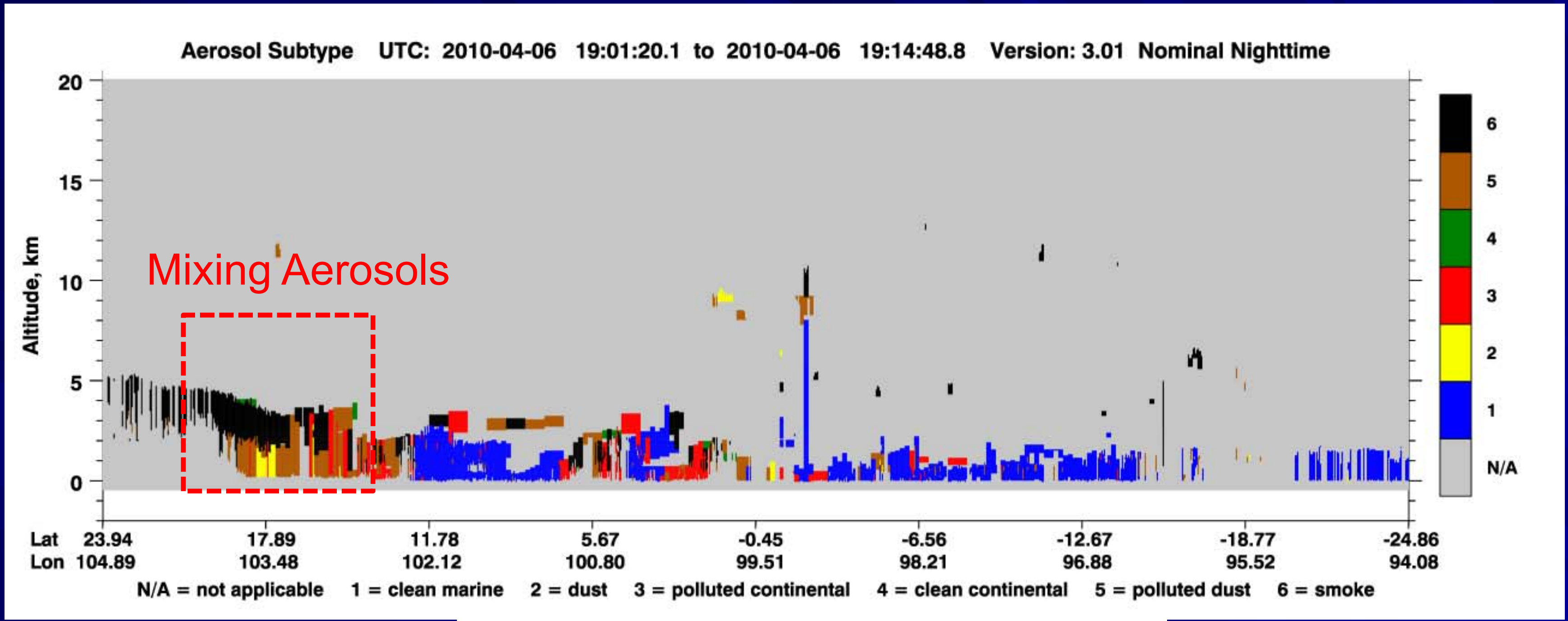
- Long range transport leads dust particles to mix with the ambient atmospheric soot easily and frequently (less than 10% of Asian dust particles were non-mixture; Iwasaka et al., 2009, …).

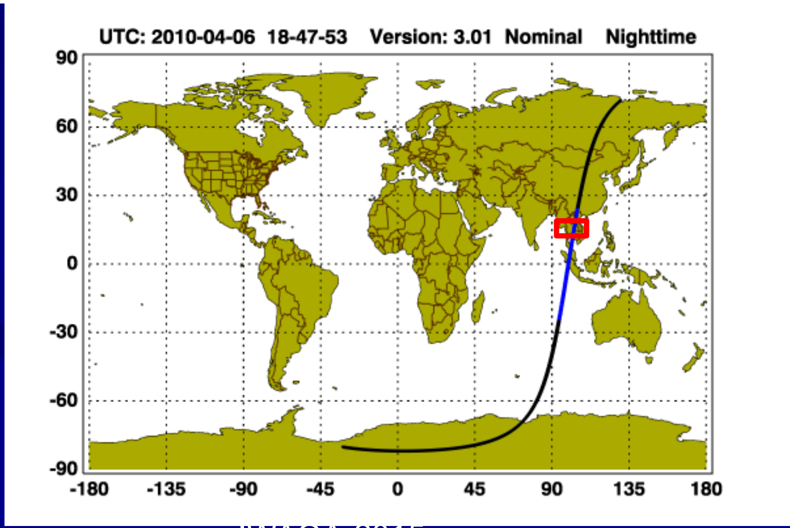




T-Lin, CSRSR NCU

Aerosol types from CALIPSO – 04/06/2010



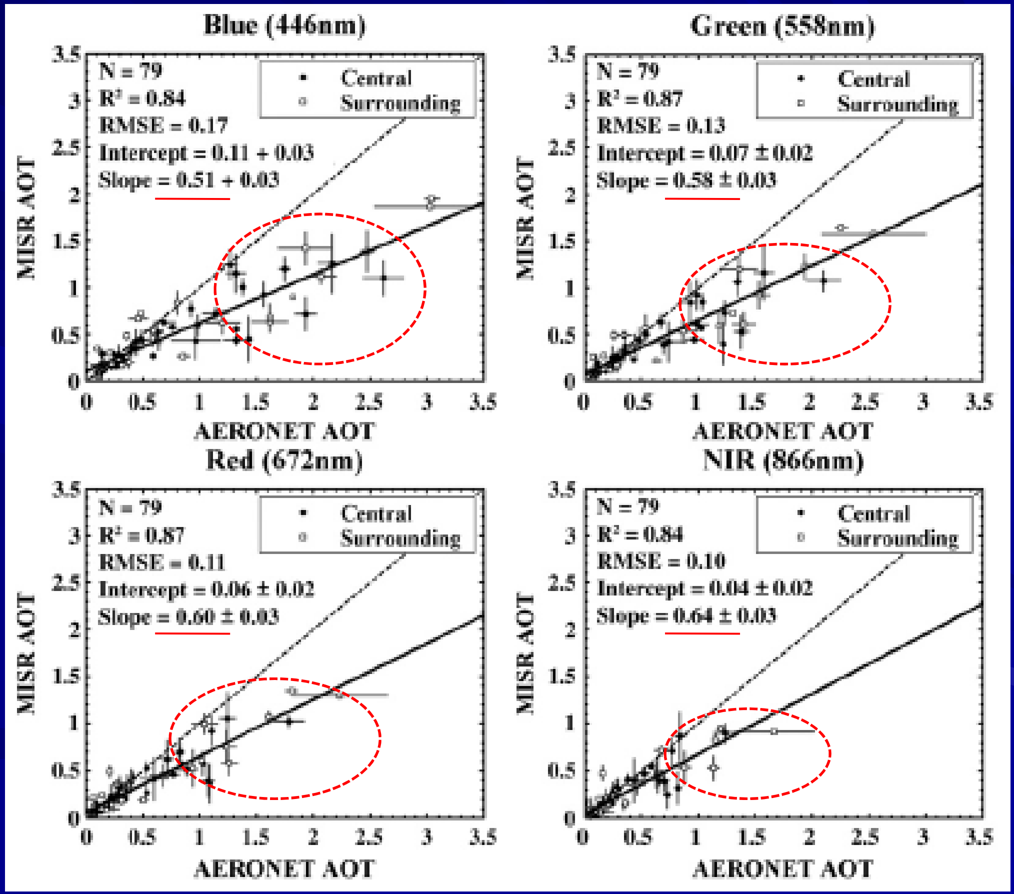


- Most dust particles are observed in coarse size with strong light scattering, while the soot is in fine size with strong absorption. Thus, the optical properties of dust particles will be dramatically altered by mixing with soot aggregates.
- Large uncertainty of retrieving aerosol properties could be induced after mixed.

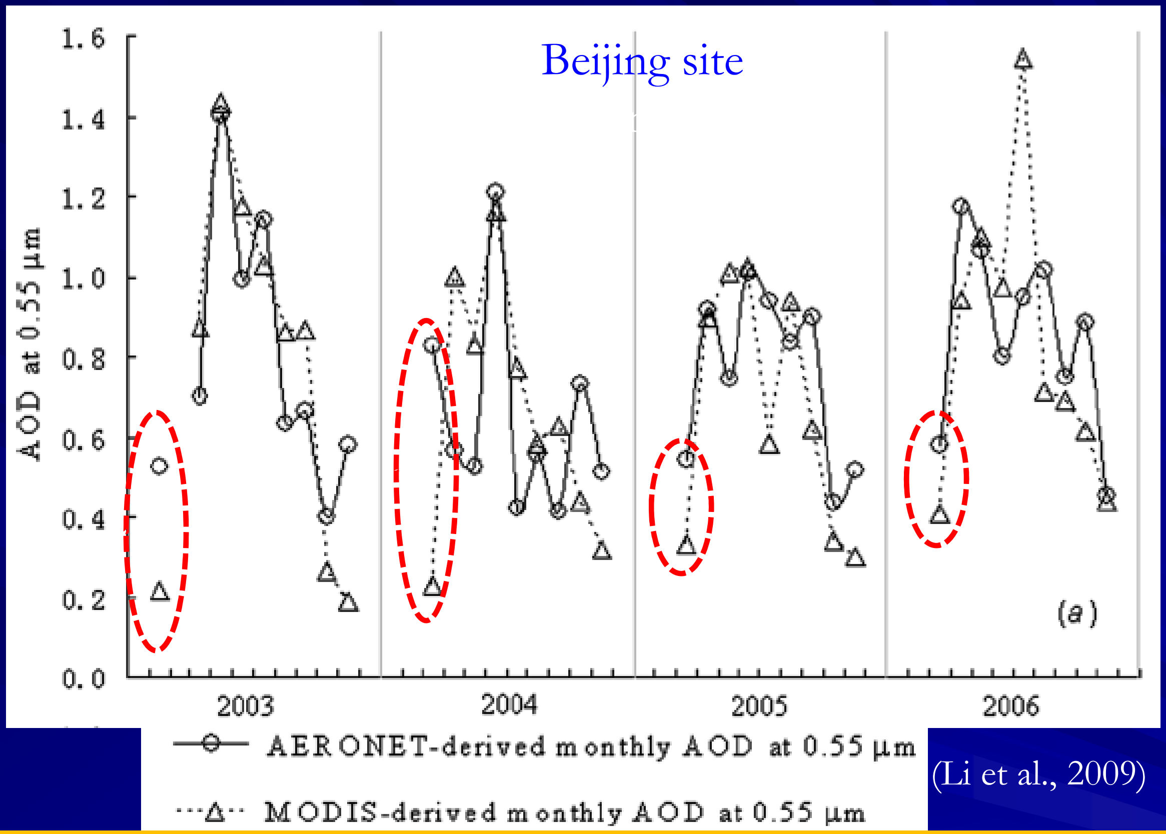
Comparison of AOD between MISR and AERONET – near Beijing site (2002-2004)

(Jiang et al., 2007)

=> The retrieval of AOD is usually under-estimated when the aerosol loading is heavy.



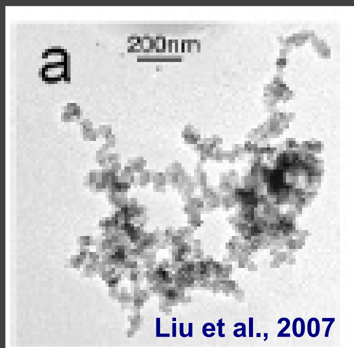
Comparison of AOD retrievals between MODIS and AERONET



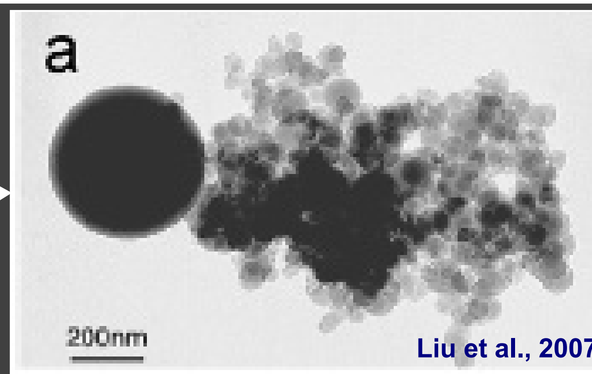
(Li et al., 2009)

=> MODIS AOD products are generally under-estimated in springtime!

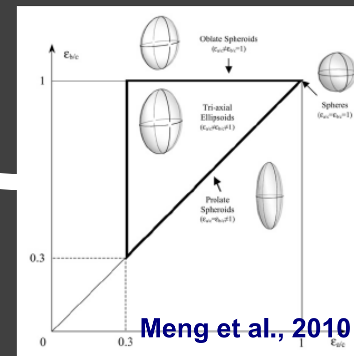
Objective: to understand the impact of mixing black carbon



Liu et al., 2007



Liu et al., 2007



Meng et al., 2010

Profile (dust) → **RTE Model (Adding/doubling method)** ← **Profile (atmosphere)**

↓

Simulations of TOA Reflectance (with different soot mixing weights)

↓

Lookup Tables for Retrieving Aerosol Properties (Deep-Blue approach)

↓

Case Study with MODIS data

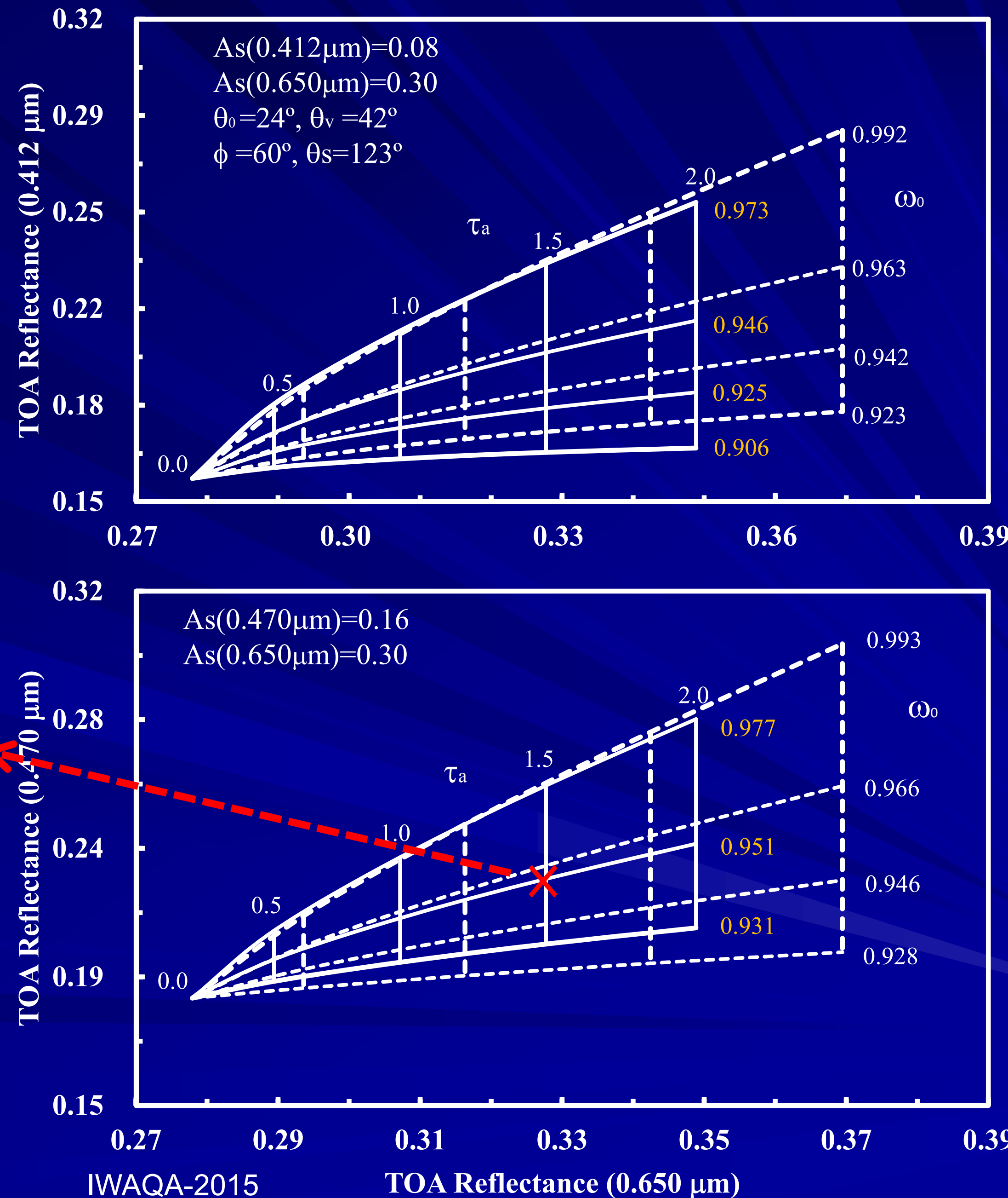
TOA reflectance of dust/soot mixture as a function of AOD & SSA

- **Deep-blue approach ~**
  - Dashe line: pure dust
  - Solid line: with **5%** soot

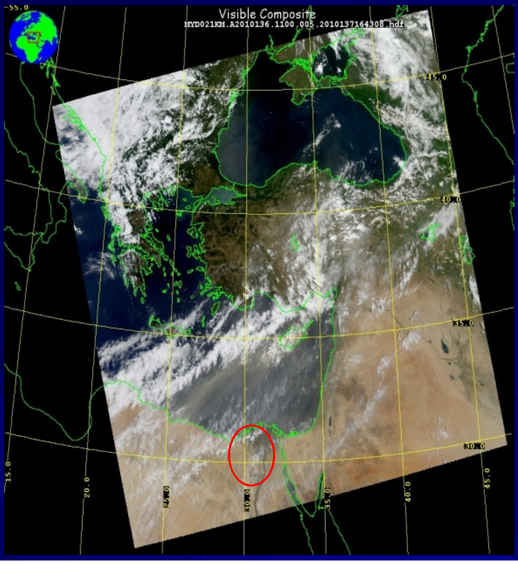
- For the mixture: the retrieval of AOD could be **underestimated** while the SSA is overestimated.

For AOD & SSA retrieval:
Polluted dust: (1.5; 0.951)
Pure dust: (1.2; 0.962)

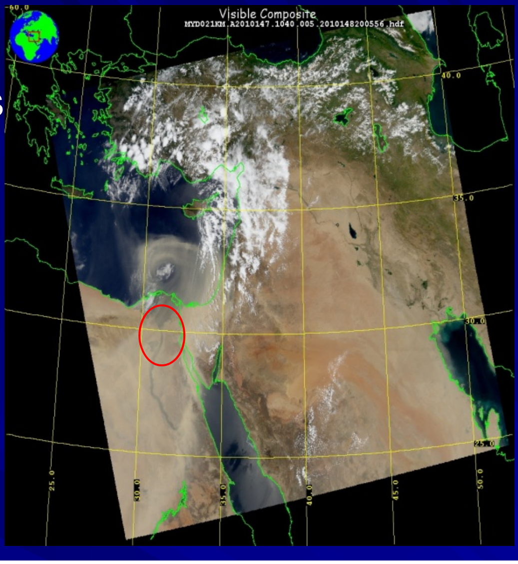
- **Consistent with the former studies!**

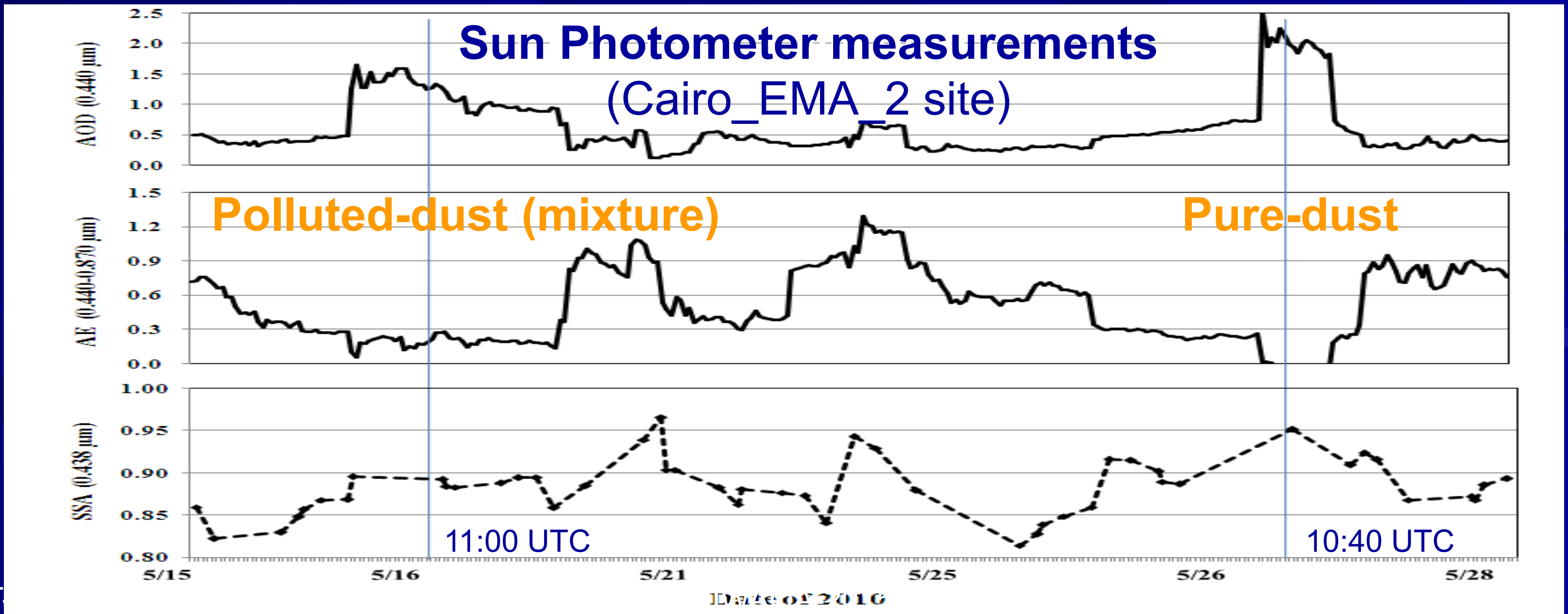


Case studies - Greater Cairo, Egypt



MODIS quick look images acquired on 16 May (left) and 27 May 2010 (right).

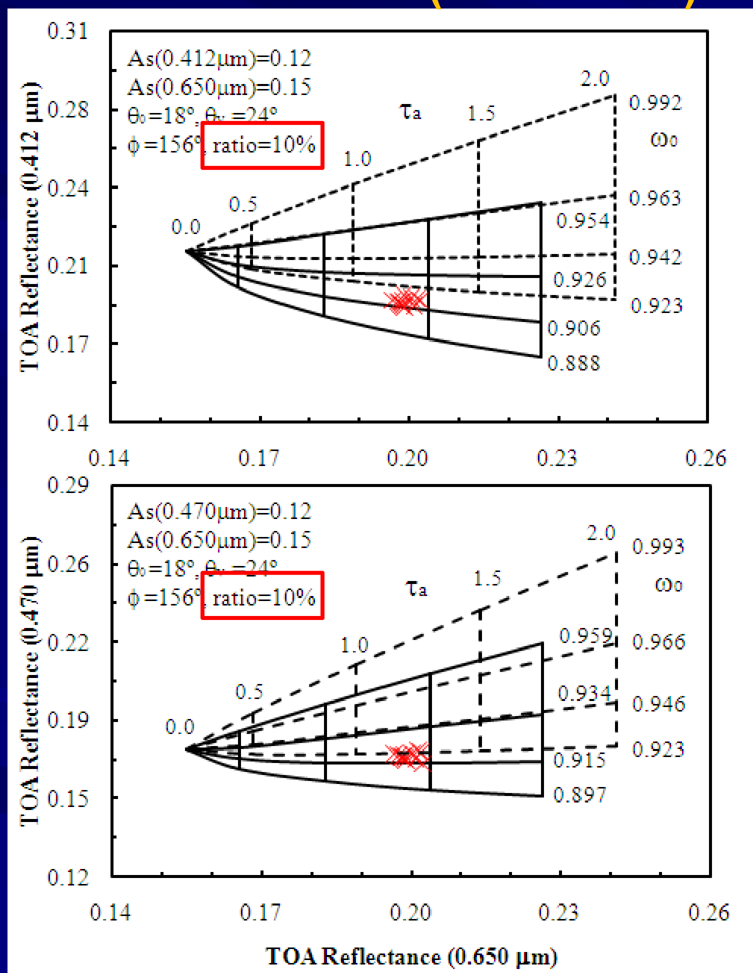




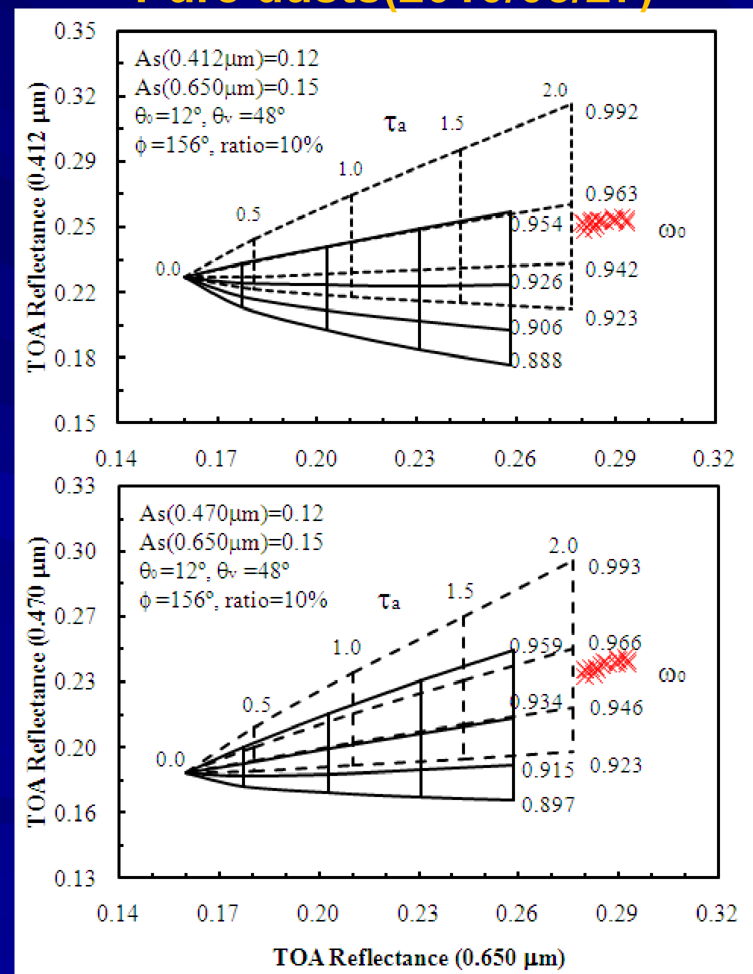
T

- With the land surface reflectivity data (MOD09), and the SSA retrieved from the Cairo_EMA_2 site (for the determination of the mixing ratio of soot aggregates), the retrievals of AOD and SSA can be determined from the lookup tables shown below;

Polluted dusts(2010/05/16)



Pure dusts(2010/05/27)



Comparison of Dust Retrievals between with and without soot aggregates around Greater Cairo

Retrieval of Dust Aerosols	Sun photometer	**With** Mixing Effect	**Without** Mixing Effect	MODIS
Case 1- polluted dusts				
AOD	1.316(0.440μm)	1.333(+1.3%)	1.159(-11.9%)	1.275(+3.1%)
SSA	0.895(0.438μm)	0.916(+2.4%)	0.932(+4.1%)	0.935(+4.5%)
Case 2- pure dusts				
AOD	2.109(0.440μm)	2.426(+12.7%)	2.167(+0.7%)	1.520(-28.0%)
SSA	0.952(0.438μm)	0.941(-1.2%)	0.947(-0.5%)	0.940(-1.3%)

Note: The values of SSA retrieval are the average of 0.412 and 0.470 μm, and the percentage in bracket is the difference of retrieval from sun photometer measurement at Cairo_EMA_2 site.

◆ Mixing Weight Determination - Dust-Soot Mixture

External Mixing Procedure:

- The extinction coefficient of a dust/soot mixture as a weighted mean of the optical properties of individual components, can be given by

$$\langle k^{ext} \rangle = w_d k_d^{ext} + w_s k_s^{ext}$$

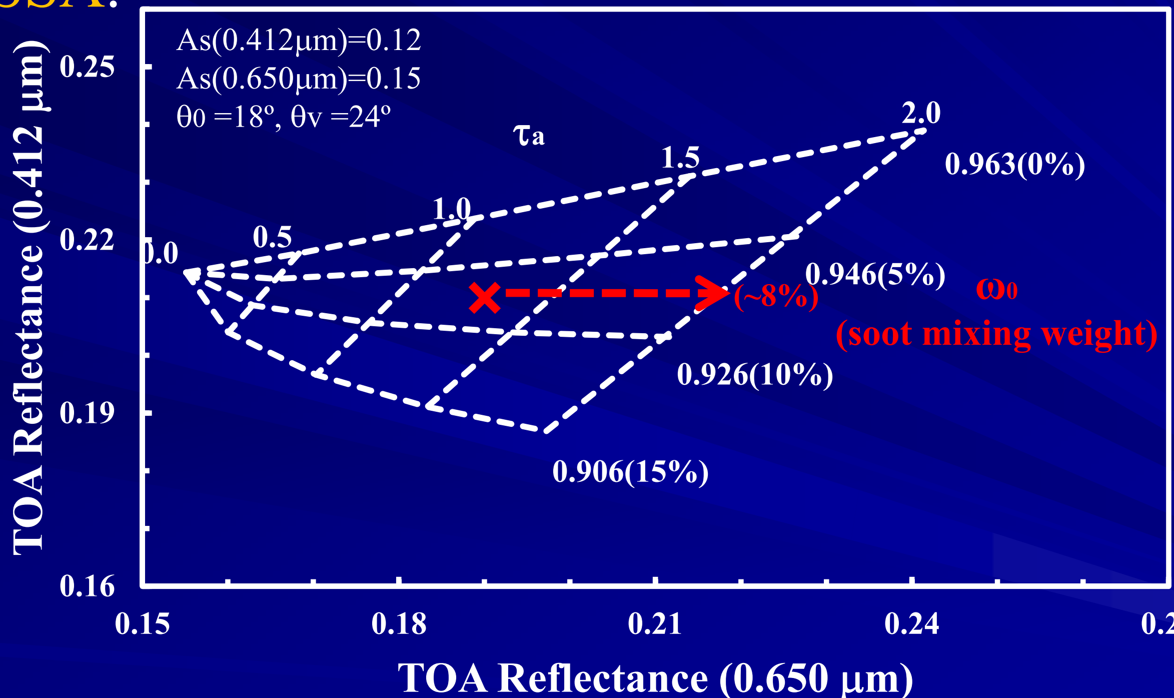
where w_d and w_s are the number-density mixing ratio of dust particles and soot aggregates, and $w_d + w_s = 1$; and are the corresponding extinction coefficients.

- The single scattering albedo (SSA) of the dust/soot mixture thus can be obtained from the ratio of scattering coefficient to extinction coefficient;

$$\langle SSA_{mixture} \rangle = \frac{(1 - w_s)k_d^{sca} + w_s k_s^{sca}}{(1 - w_s)k_d^{ext} + w_s k_s^{ext}}$$

- If the SSAs (or refractive index) of dusts and soot aggregates can be considered as stable (constant) for a specific region, the mixing weights (w_d, w_s) can be derived from the SSA value of dust/soot mixture.

- For example, the representative REFI (the imaginary part of refractive index) of regional dust particles can be firstly provided by the long-term AERONET observations. Thus the mixing weights of dust/soot mixtures can be determined from the observed value of SSA.



Simulated TOA reflectance as a function of AOD and SSA(mixing weights) for 412 versus 650nm channel when REFI of dust particle is 0.002.

The location of AERONET sites

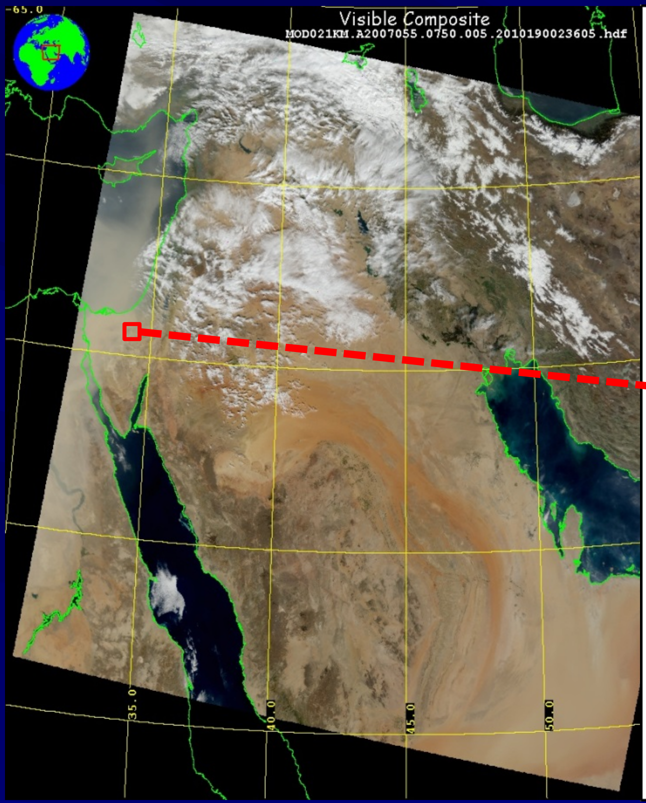
SEDE BOKER, ISRAEL

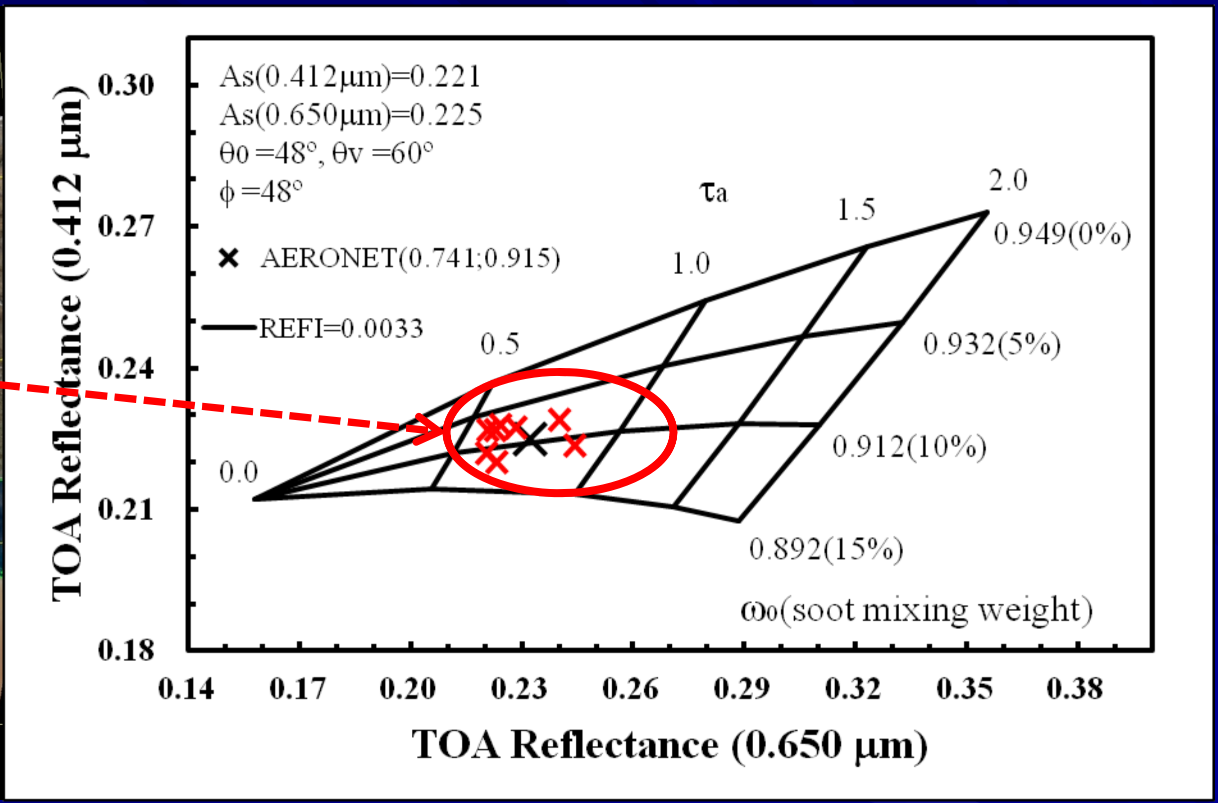
■ AOD more than 1.5 for pure dusts (17 of 23056 level 1.5 data selected)

Date	Time	REFR(441)	REFR(673)	REFI(441)	REFI(673)	alpha440-870	tau440
2000/5/04	11:40:00	1.6	1.5977	0.00229	0.001025	-0.016876	1.547848
2002/3/19	07:50:52	1.5952	1.5652	0.003102	0.000649	0.079057	3.626158
2003/5/30	13:40:15	1.6	1.5893	0.003367	0.001091	-0.003869	1.575209
2003/5/30	14:08:32	1.6	1.5843	0.003516	0.001181	-0.010097	1.706036
2004/5/30	14:09:00	1.5807	1.5553	0.003603	0.001593	0.044293	1.539797
2006/5/07	13:57:12	1.4821	1.4693	0.002675	0.001046	0.086316	1.512361
2007/2/24	12:56:23	1.486	1.4502	0.003481	0.001077	0.076463	2.034286
2007/2/24	13:10:19	1.6	1.5435	0.004153	0.001192	0.074684	2.150239
2009/9/12	13:00:26	1.6	1.5972	0.002917	0.000913	-0.023909	1.7648
2010/3/15	13:21:54	1.6	1.6	0.003252	0.001504	-0.032249	2.337895
2011/2/19	13:52:00	1.6	1.5289	0.002808	0.001219	-0.066568	1.617715
2011/5/17	07:39:30	1.5459	1.5204	0.005304	0.001739	0.076569	1.827901
2011/5/17	13:34:23	1.5412	1.5291	0.00285	0.000705	0.068758	1.734782
2011/5/17	14:02:30	1.525	1.5223	0.002712	0.000743	0.073211	1.610904
2012/3/20	12:56:43	1.5649	1.5165	0.004457	0.002661	-0.046357	1.531074
2012/3/20	13:27:15	1.5005	1.4656	0.003548	0.002234	-0.059828	1.677769
2012/3/20	14:18:26	1.472	1.4523	0.003189	0.001365	-0.056459	1.601853

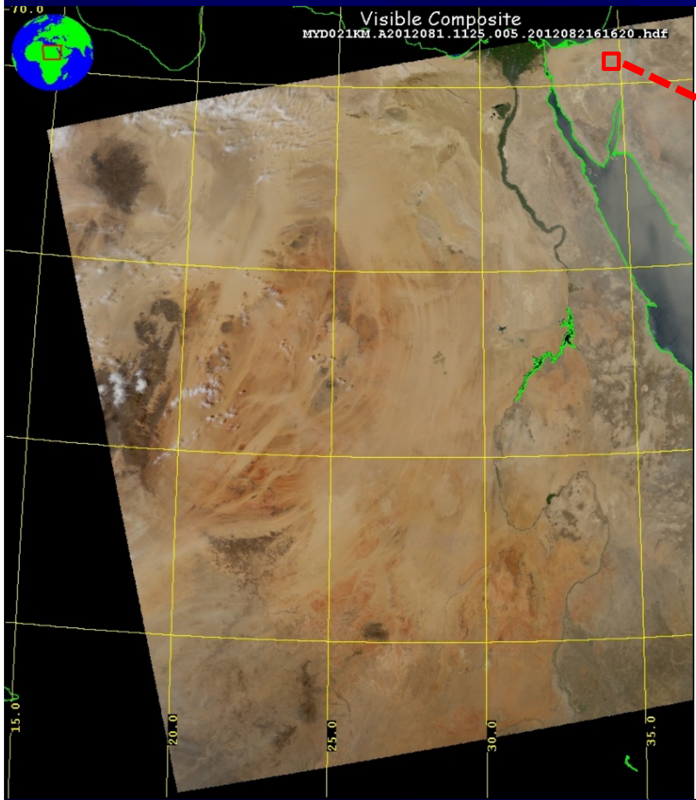
The mean of REFI is 0.003366 with 21%(σ is 0.000735) uncertainty.

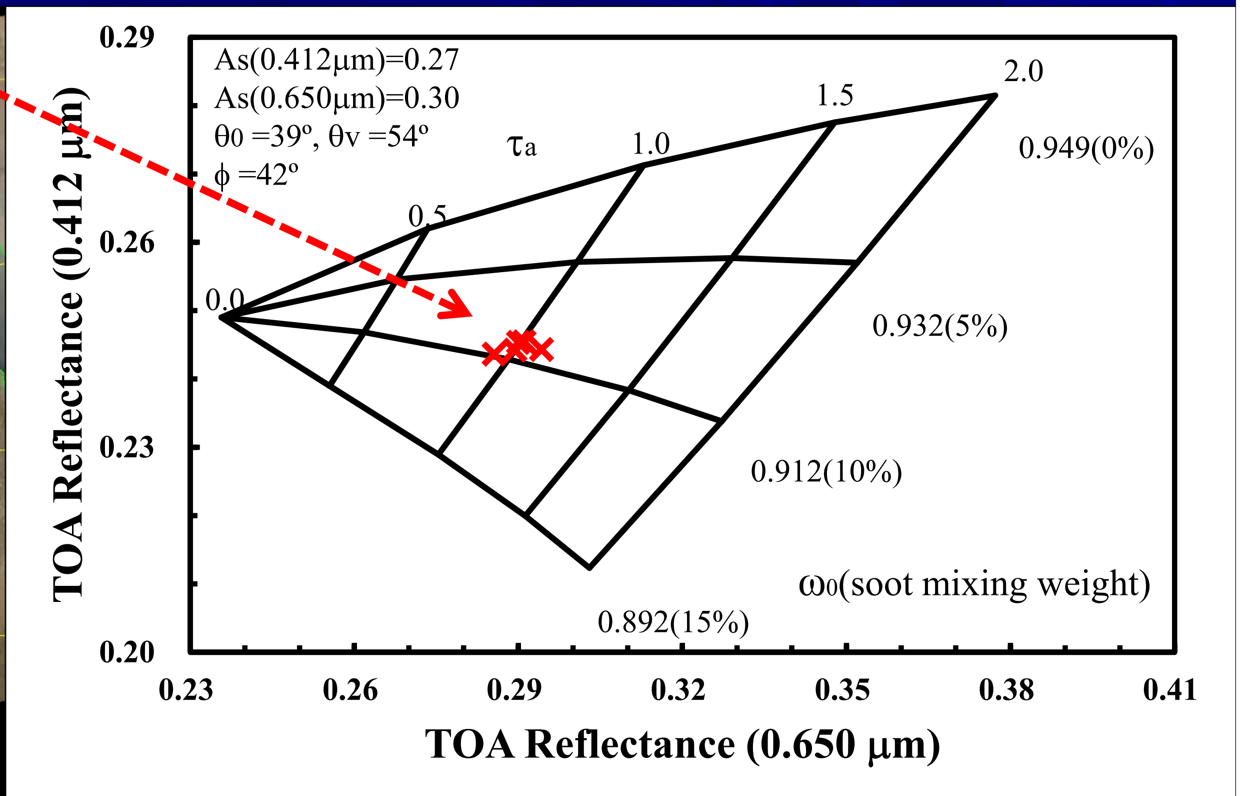
Polluted dust (2007/2/24)





Polluted dust (2012/3/21)

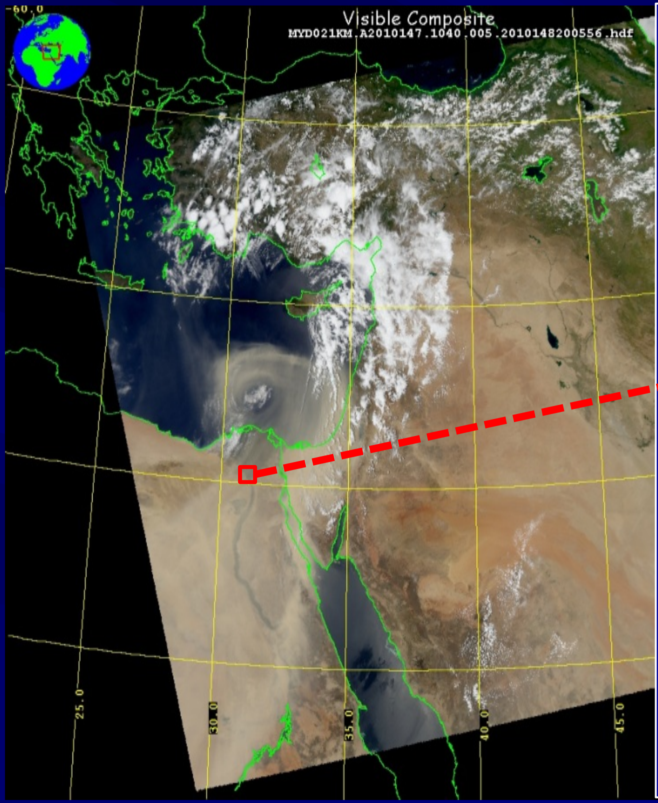


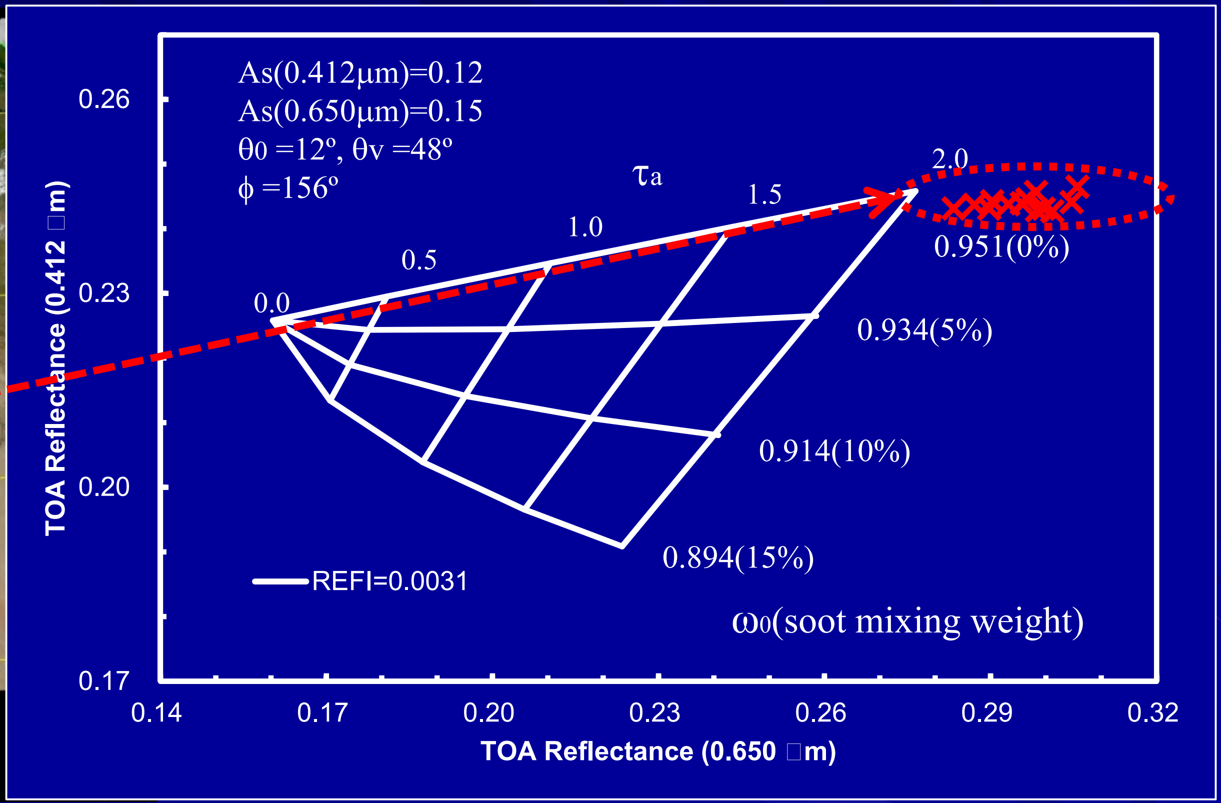


The location of AERONET sites

- The Middle East is a region where aerosols from different origins are mixed in variable proportions, serving as a proper region for the validation of the dust/soot mixture in this study, MODIS/Aqua image at 1105 2007055.

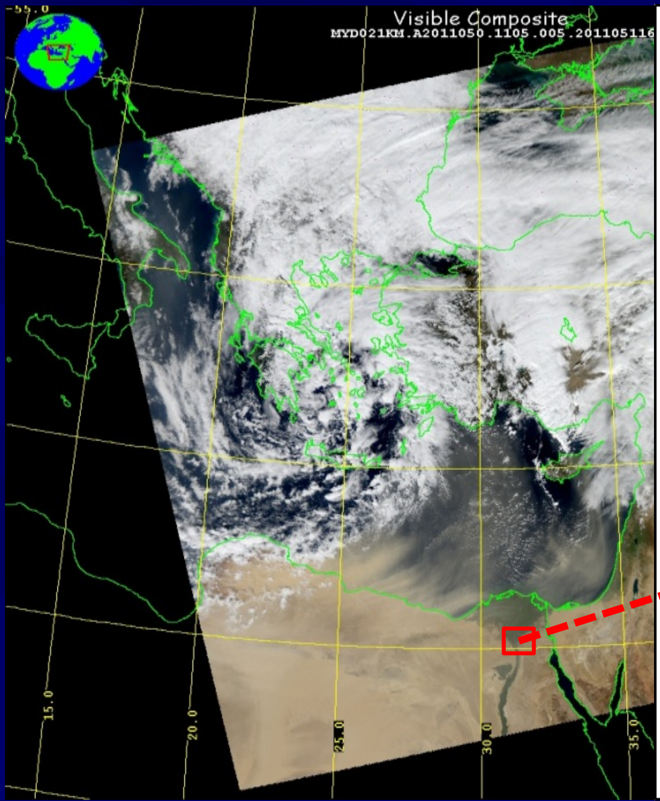
Case of Pure Dust - May 27, 2010

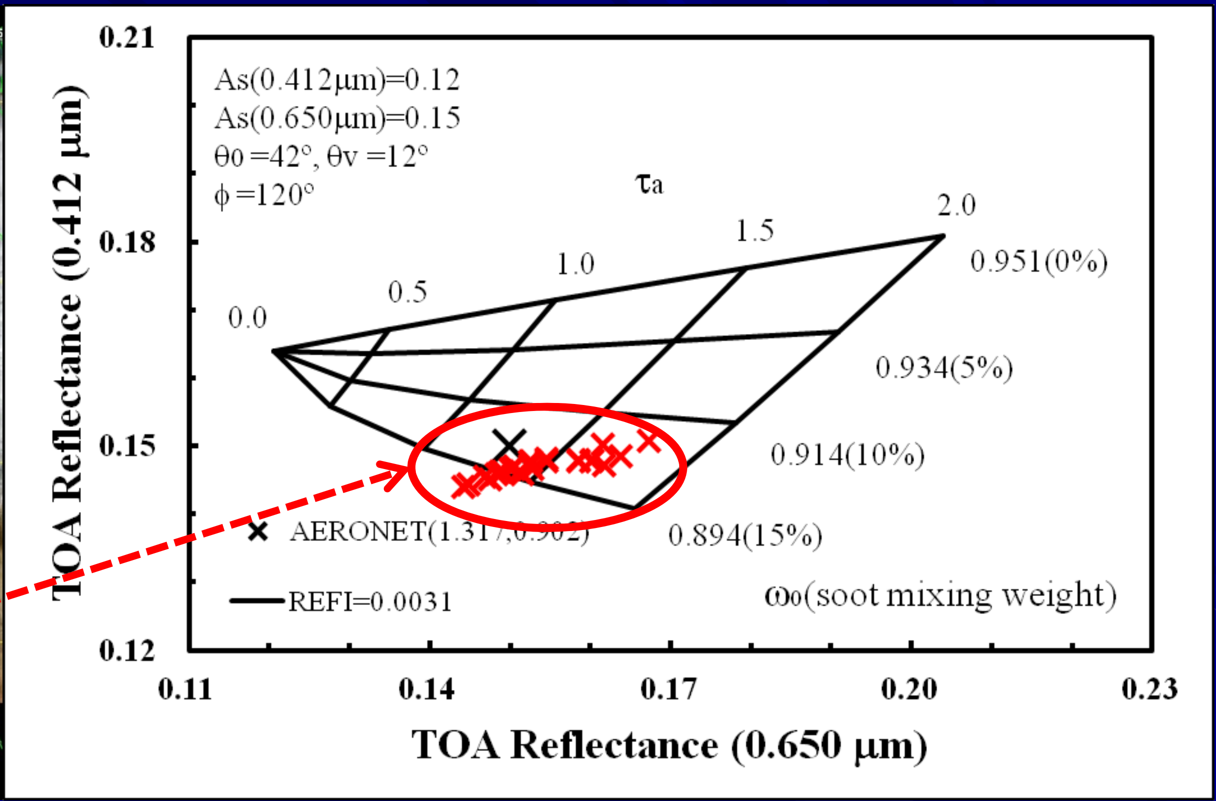




➢ **The TOA reflectance from MODIS observations suggest that the mixing weights of soot aggregates close to 0% (pure dusts).**

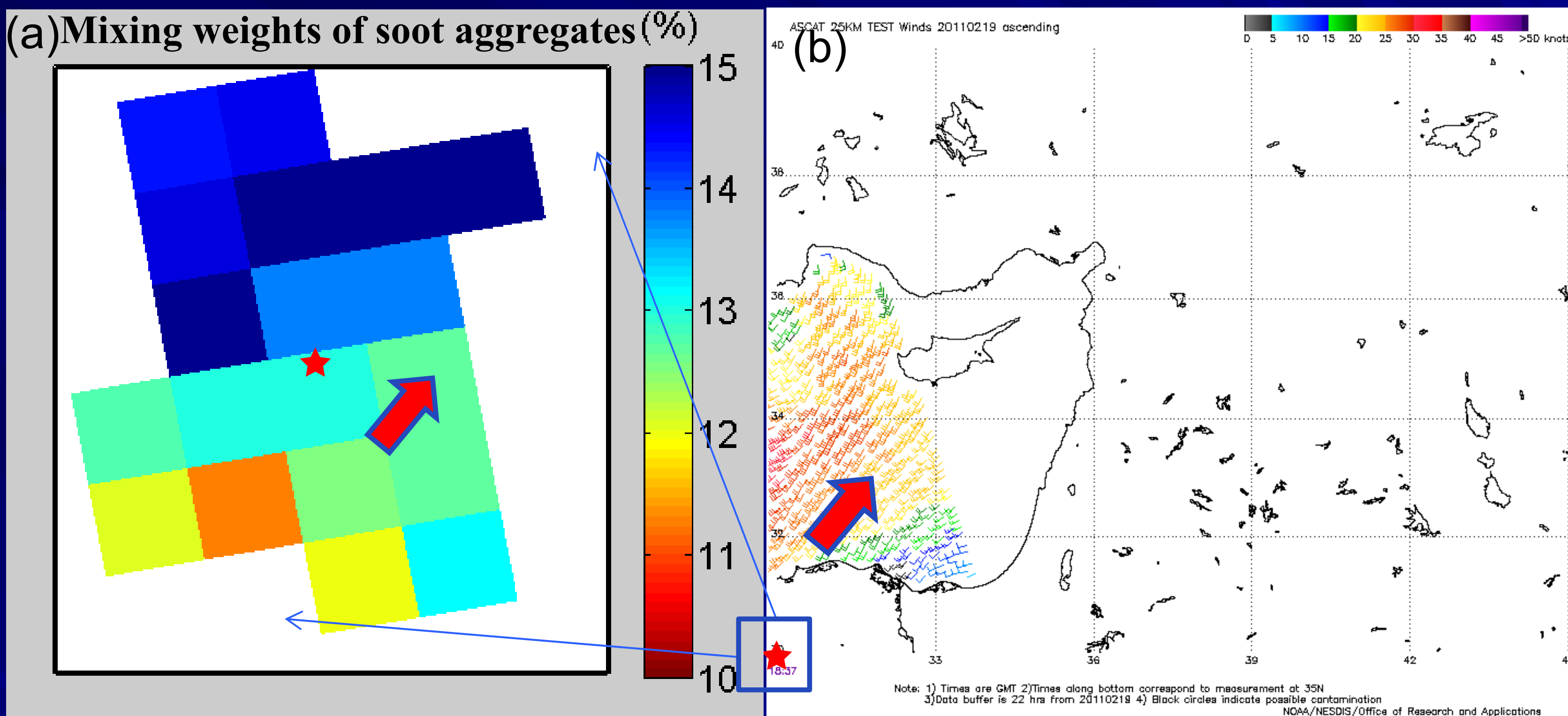
Case of Polluted Dust- Feb. 19, 2011





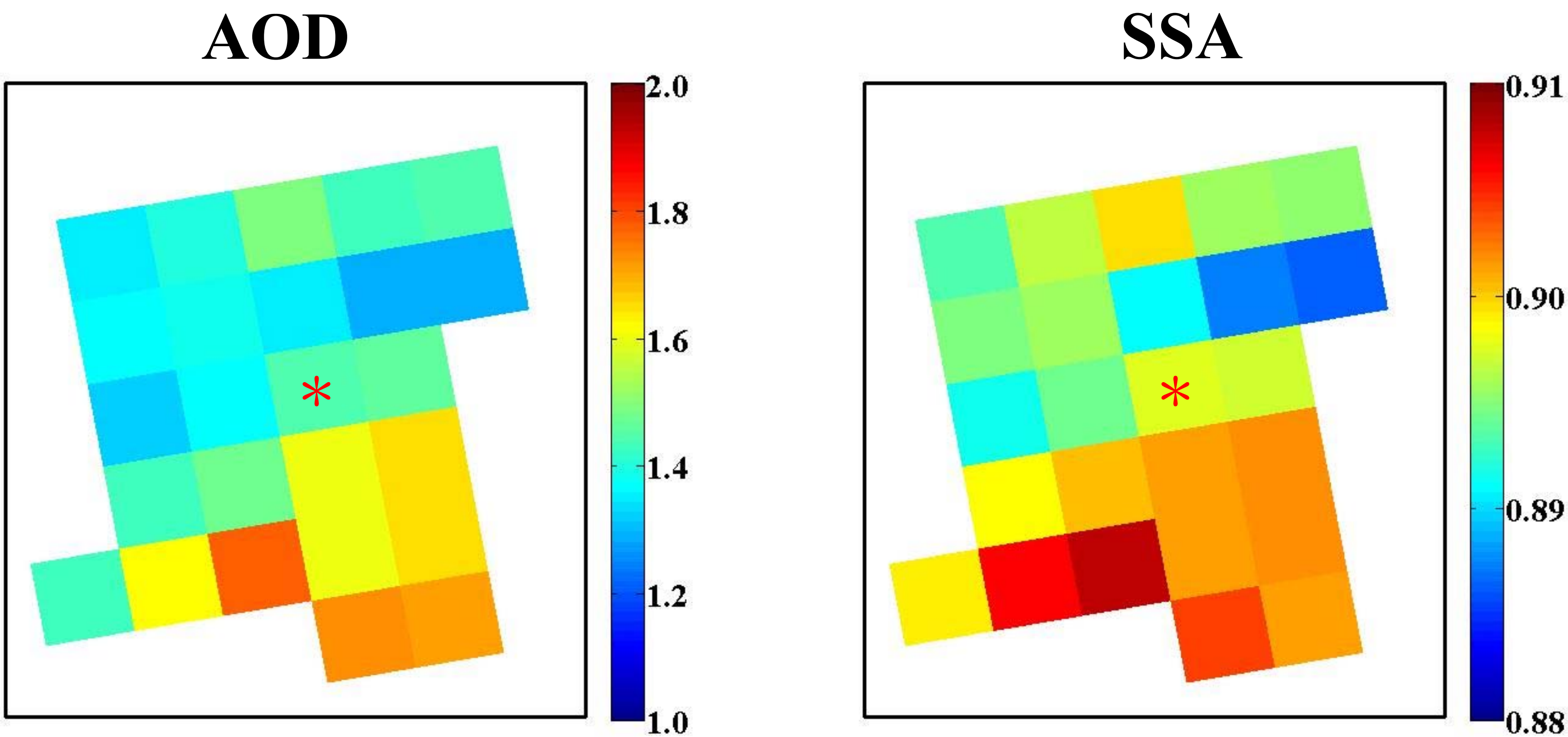
- The TOA reflectance from MODIS observations indicate the mixing weights of soot aggregates over test area distributing from 11% to 16%.

Spatial Distribution of Soot aggregates Mixing Weights & Wind Field(ASCAT data)



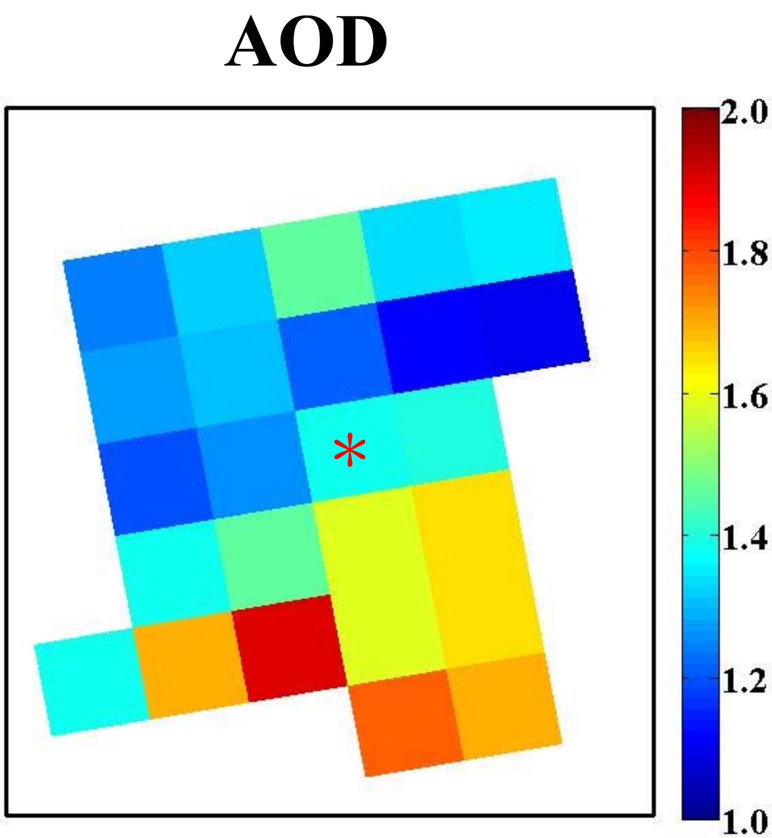
The spatial distribution of mixing weights follows the near sea surface wind field.

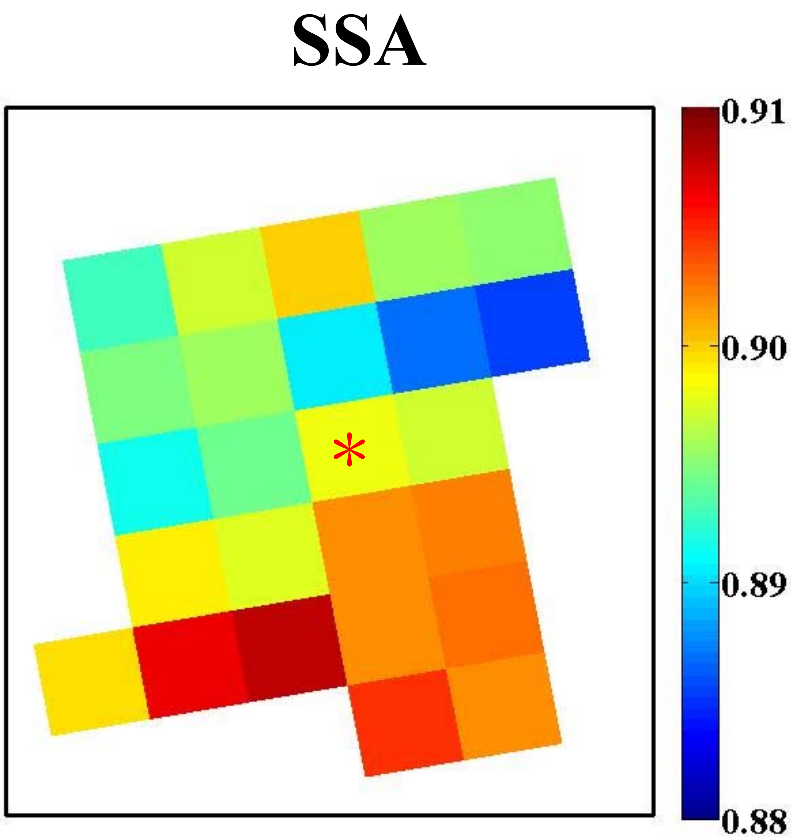
The retrievals of AOD & SSA with Various Mixing Weight
Feb. 19, 2011



* The location of Cairo EMA site

The retrievals of AOD & SSA with Fixed Mixing Weight (13%) Feb. 19, 2011





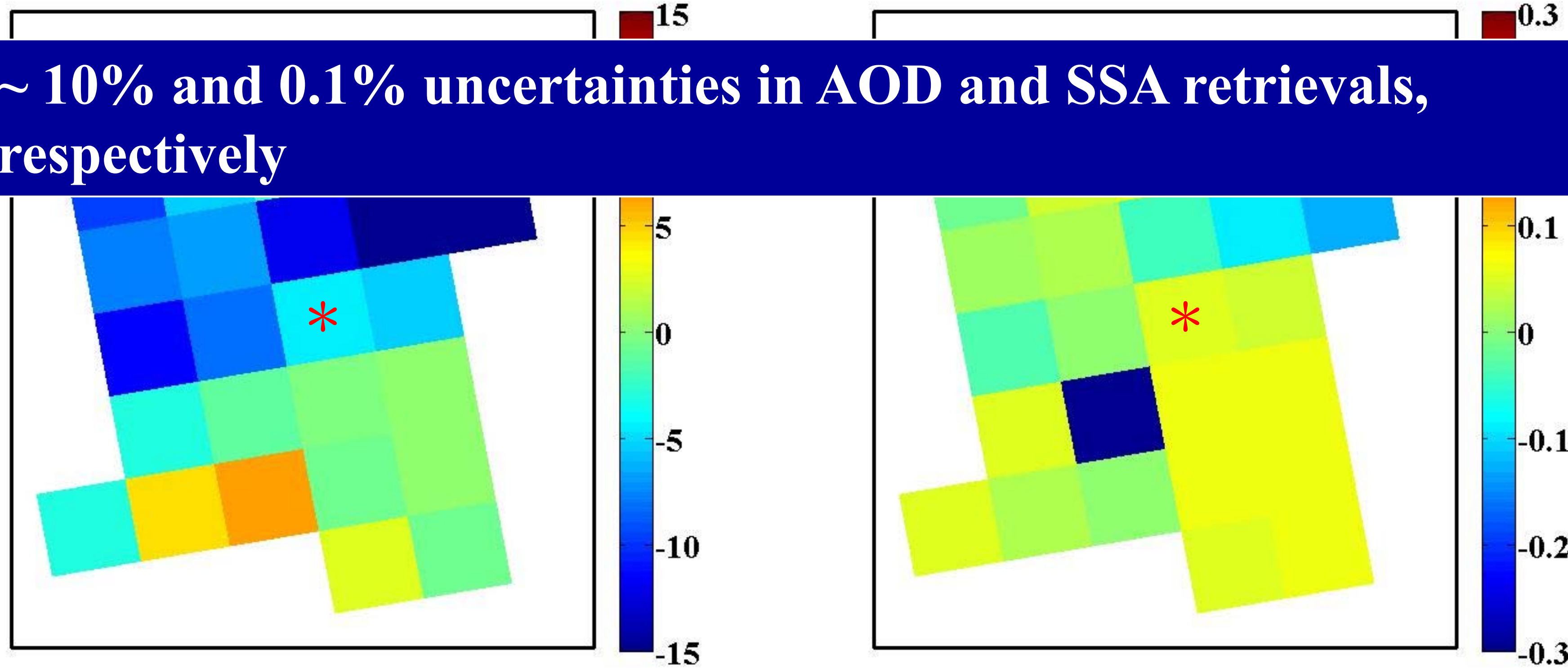
* The location of Cairo EMA site

The comparison of AOD & SSA products on Cairo site, Feb. 19, 2011

Retrieval of Dust Aerosols	AERONET measurement	With Fixed mixing weight (13%)	With Various mixing weigh (11~16%)	MODIS Products
AOD	1.317	1.384(+5.09%)	1.444(+9.64%)	0.715(-45.71%)
SSA	0.902	0.898(-0.43%)	0.897(-0.48%)	0.911(+1.11%)

The Spatial Difference between with Fixed & Various Mixing Weight (in Percentage)

AOD **SSA**



✓ ~ 10% and 0.1% uncertainties in AOD and SSA retrievals, respectively

* The location of Cairo EMA site

Discussions

With the development of remote sensing science and technology, the satellite observations can be applied to

- Discrimination of aerosol type – mineral dust, smoke particles and anthropogenic pollutant (mixing area)
- Determination of black carbon mixing weight with MODIS & AERONET data (sulfate)
- It seems helpful to mapping the uncertainty of aerosol effects on radiative forcing with satellite observations.

Contact:

Tang-Huang Lin

thlin@csrsr.ncu.edu.tw

http://ersl.csrsr.ncu.edu.tw/

Thanks for your attention!