AERONET's Development and Contributions through Two Decades of Aerosol Research

How did we get there?

What has been achieved?

What is the next step?

CPS/Kobe University March 28, 2017

Brent Holben NASA/GSFC

AERONET- The ground based Satellite

- Research Aerosol Network
- Public domain database
- Measured AOD
- Retrieve Microphysical and Radiative aerosol properties

Mission Objectives:

- Characterize aerosol optical properties
- Validate Satellite & model aerosol retrievals
- Synergism with Satellite obs., ESS and CC

The dawn of networks

F.E. Volz (1959) developed the Volz sun photometer
- Small, portable and accurate instruments
- Schott interference filters
- Stable photodiodes

Flowers et al. 1969
- US Turbidity Network
- 5 year record
- Monthly averages
- 43 sites

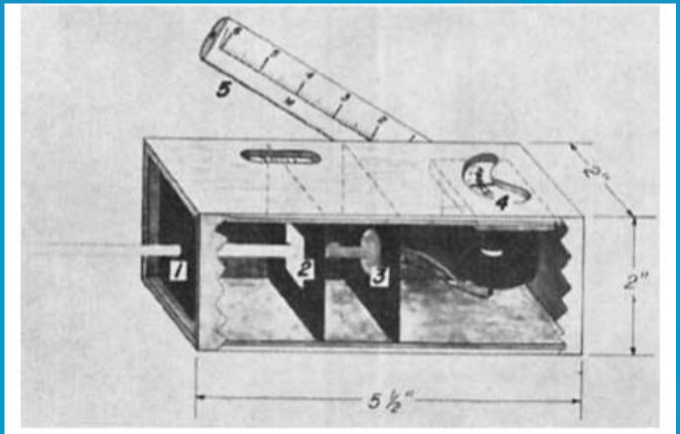


FIG. 1. Volz type G sunphotometer: 1) aperture; 2) filter; 3) selenium photocell; 4) microammeter; and 5) diopter.

M. D. King et al., 1978
- Size distribution from Inversion of Spectral AOD

Anybody can take these measurements!

Observations on every continent
- •National Met programs
- •University scientists
- •NASA scientists
- •Students
- •Sailors

BAPMoN (Background Air Pollution Monitoring Network)
- •WMO program to coordinate and archive measurements
- •15 yr global record

Add the sky radiance

Tanaka, M. et al.,1982

Nakajima, T. et al., 1983, ‘89, ‘96

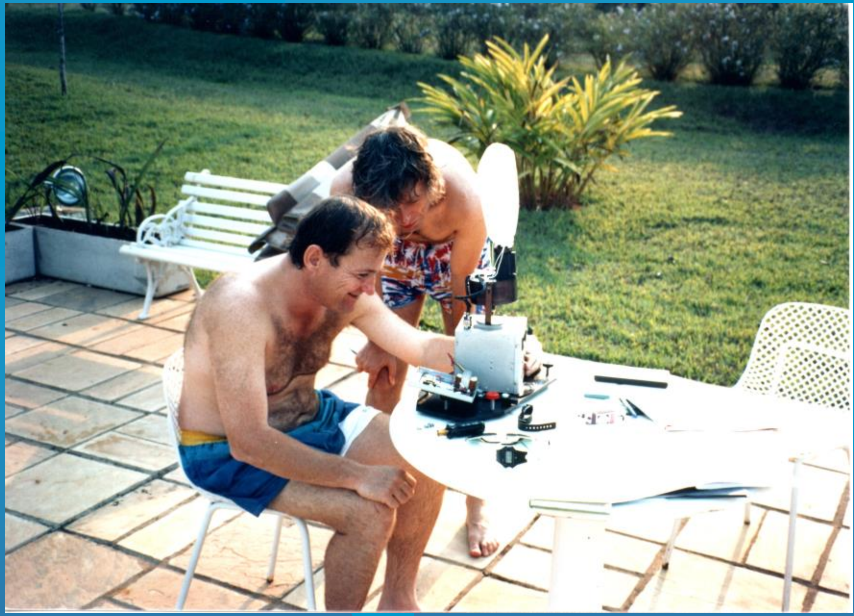
- Inversion yielded improved particle size distributions
- skyrad.pak
- Required accurately pointing sun sky radiometer
- Lost portability/convenience

What did we learn in the ‘80s?

- Maintaining more than two radiometers for more than 2 months is difficult at best
- BAPMoN (Background Air Pollution Monitoring Network)
- ‘… inadequate for contemporary needs.’ WMO/GAW Rpt. # 101, 1993

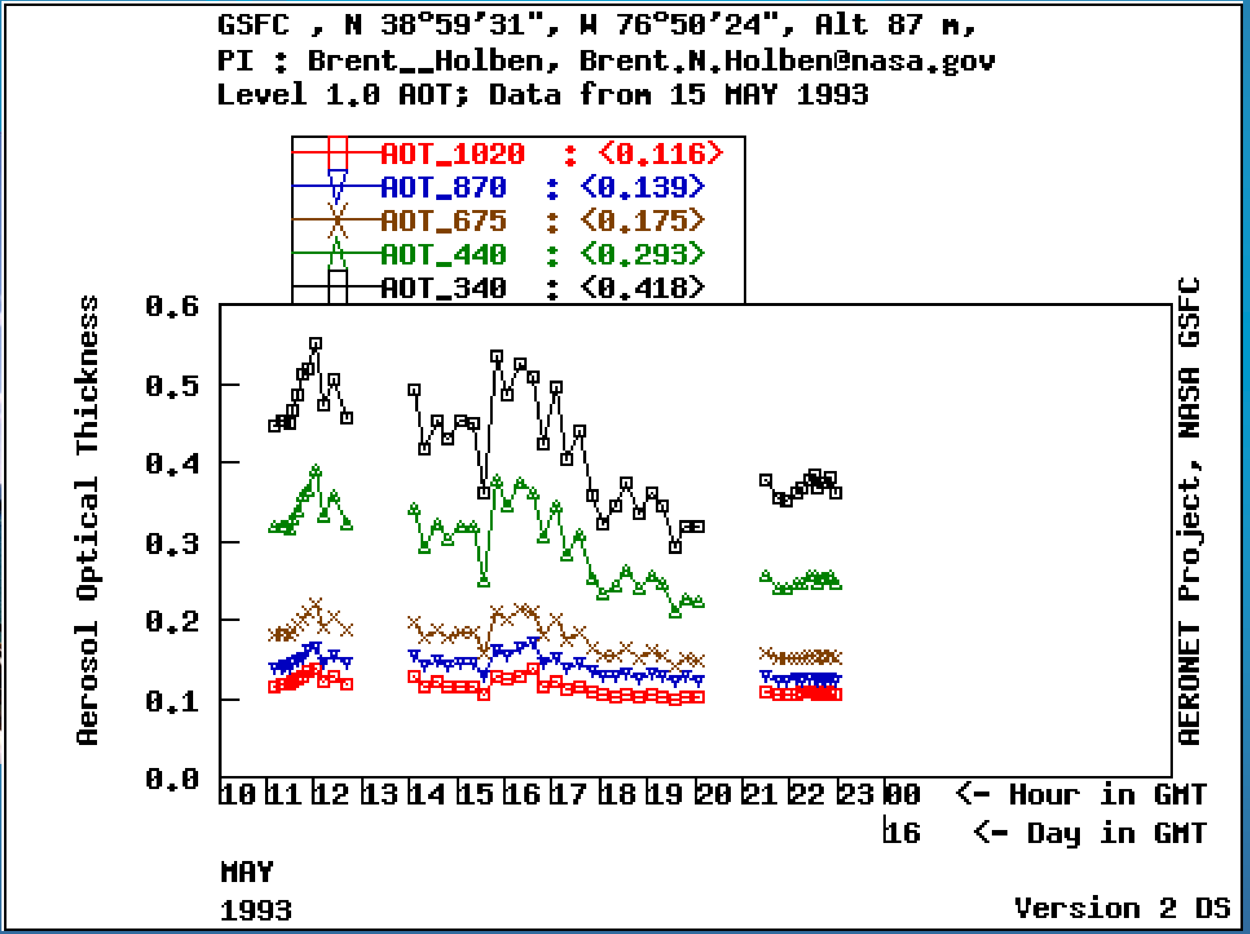
The Hazy Beginning

Kaufman and Tanre, 1989



Smirnov with J.P. Buis

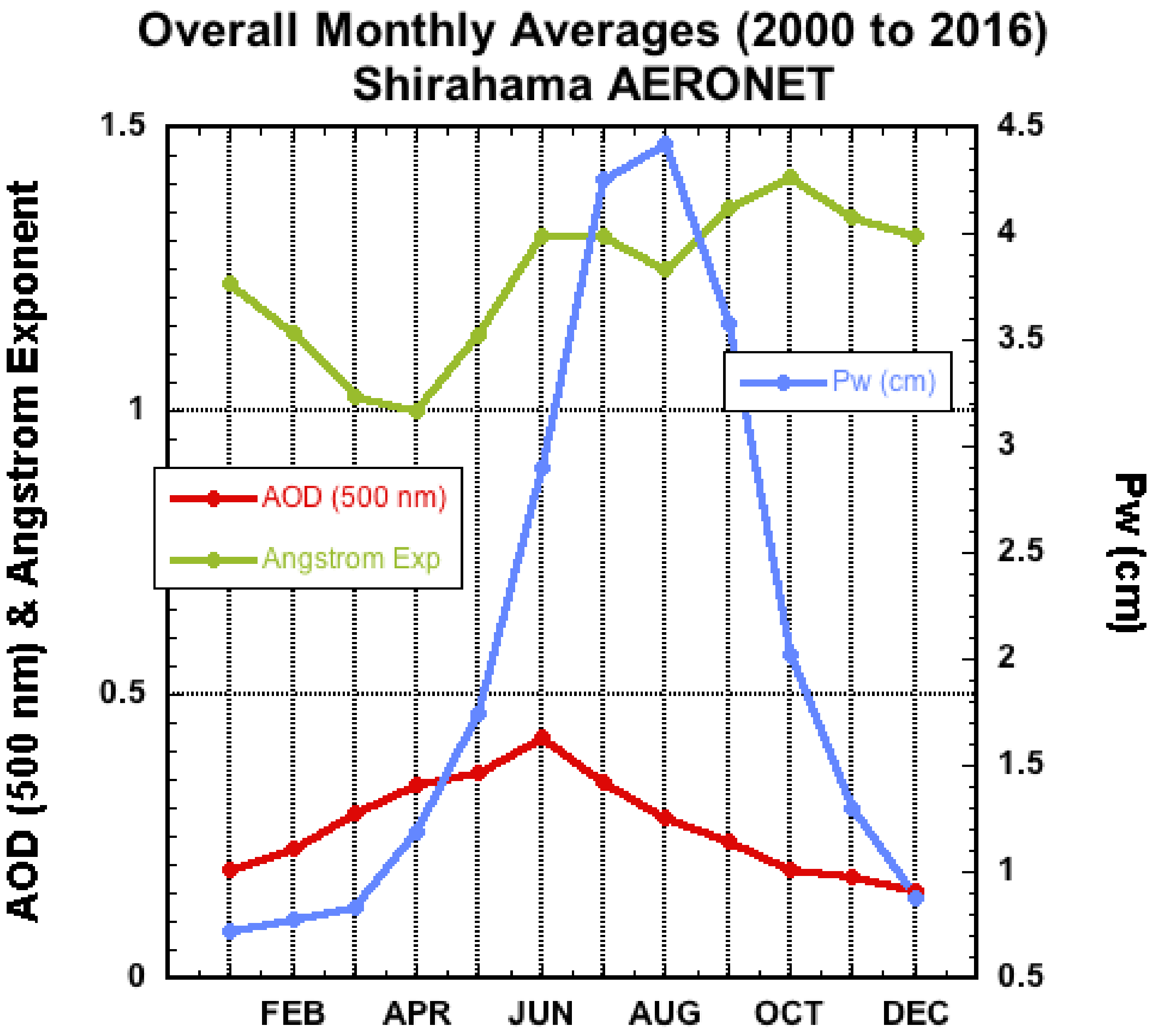
AERONET's First Light (1993)



The AERONET Network Model

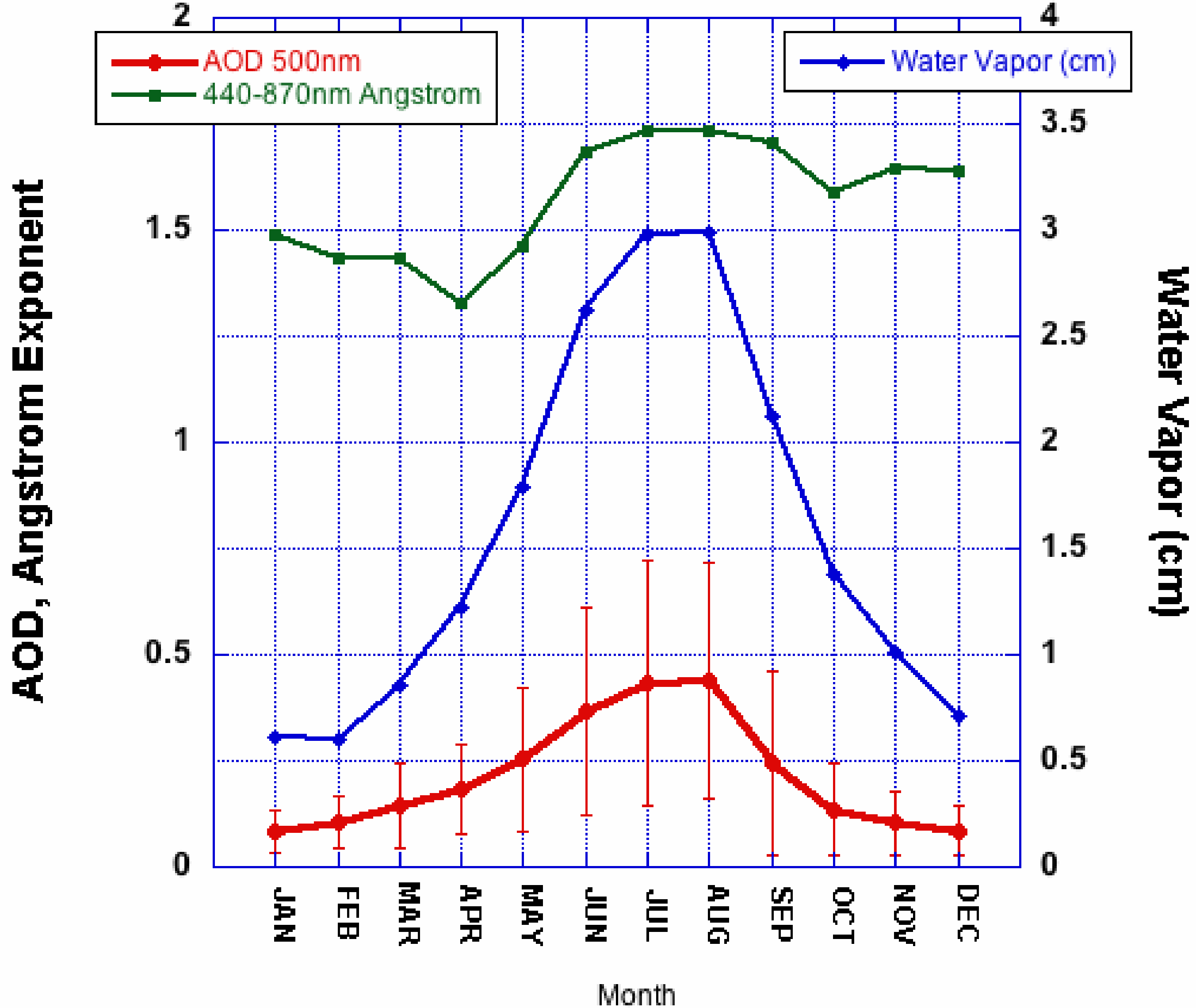
- Impose standardization
  – Instrumentation
  – Calibration
  – Processing
  – Open NRT Data Archive
  – QA Data
- Goal: Public Domain Research Database
- Attract Contributors


1993

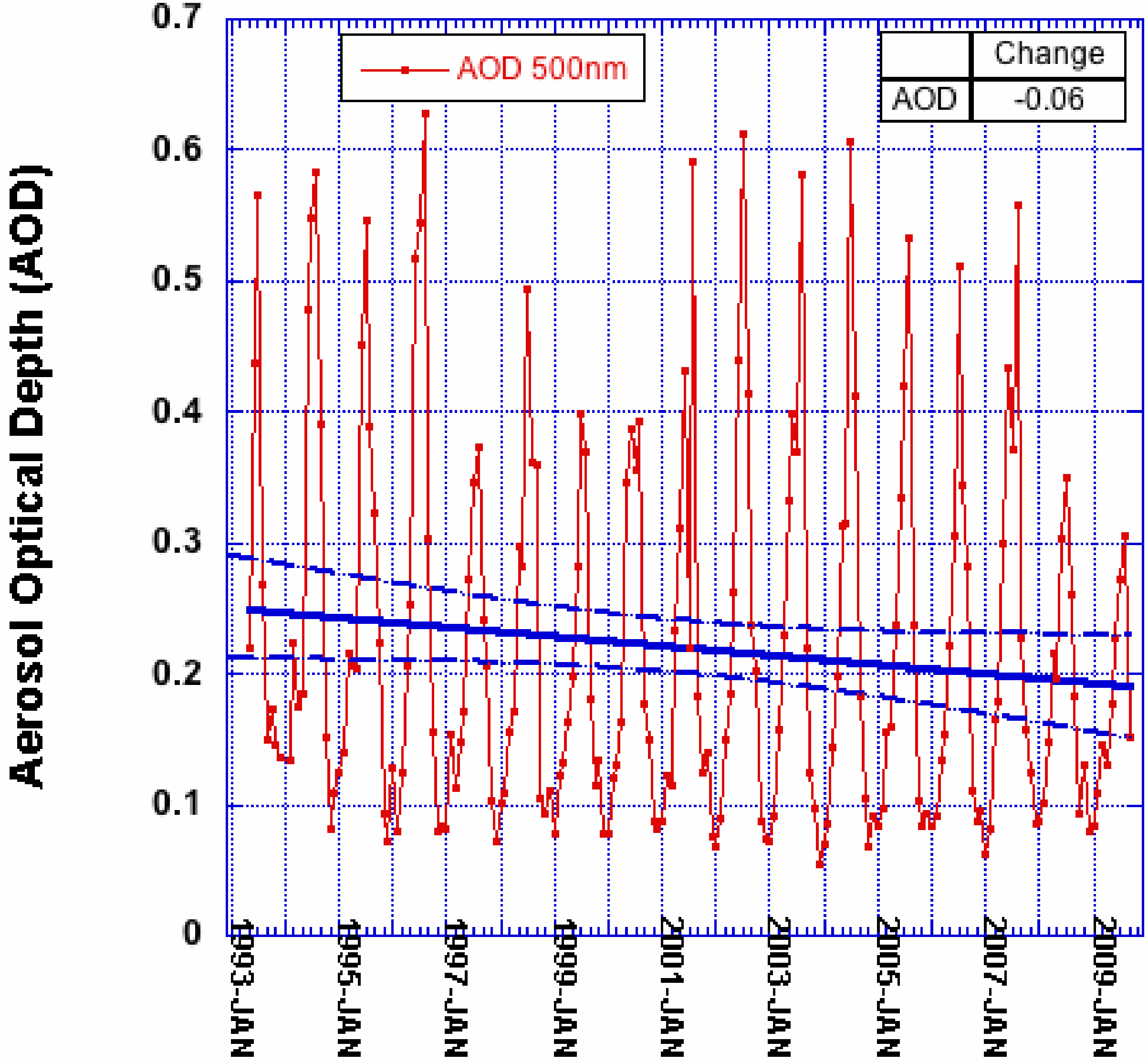


Overall Monthly Averages (2000 to 2016)
Shirahama AERONET
AOD (500 nm) & Angstrom Exponent
Pw (cm)
AOD (500 nm)
Angstrom Exp
Pw (cm)
1.5
1
0.5
0
4.5
4
3.5
3
2.5
2
1.5
1
0.5
FEB
APR
JUN
AUG
OCT
DEC

Overall Monthly Average (1993-2009)
GSFC

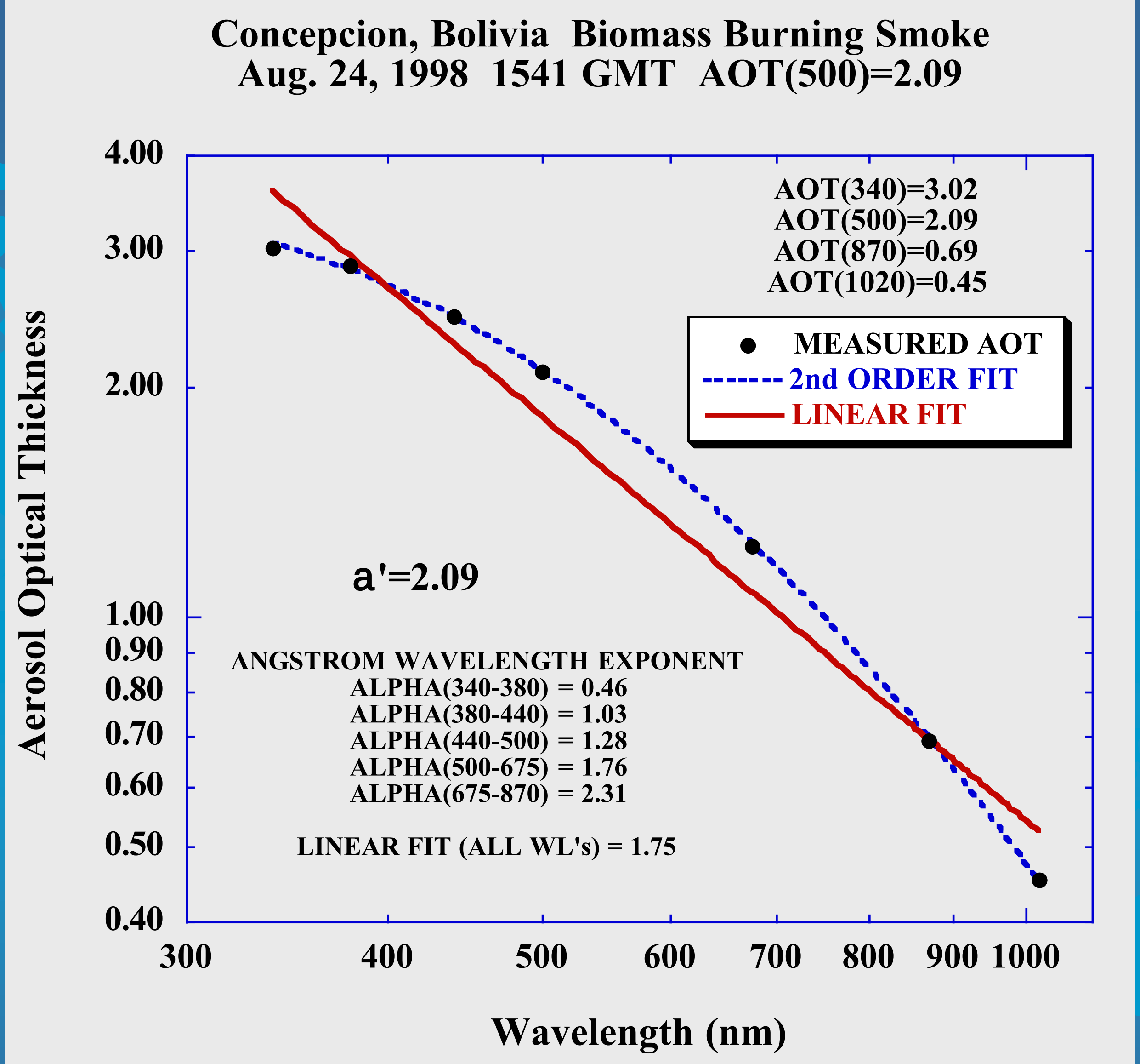


Trends (1993-2009)
GSFC

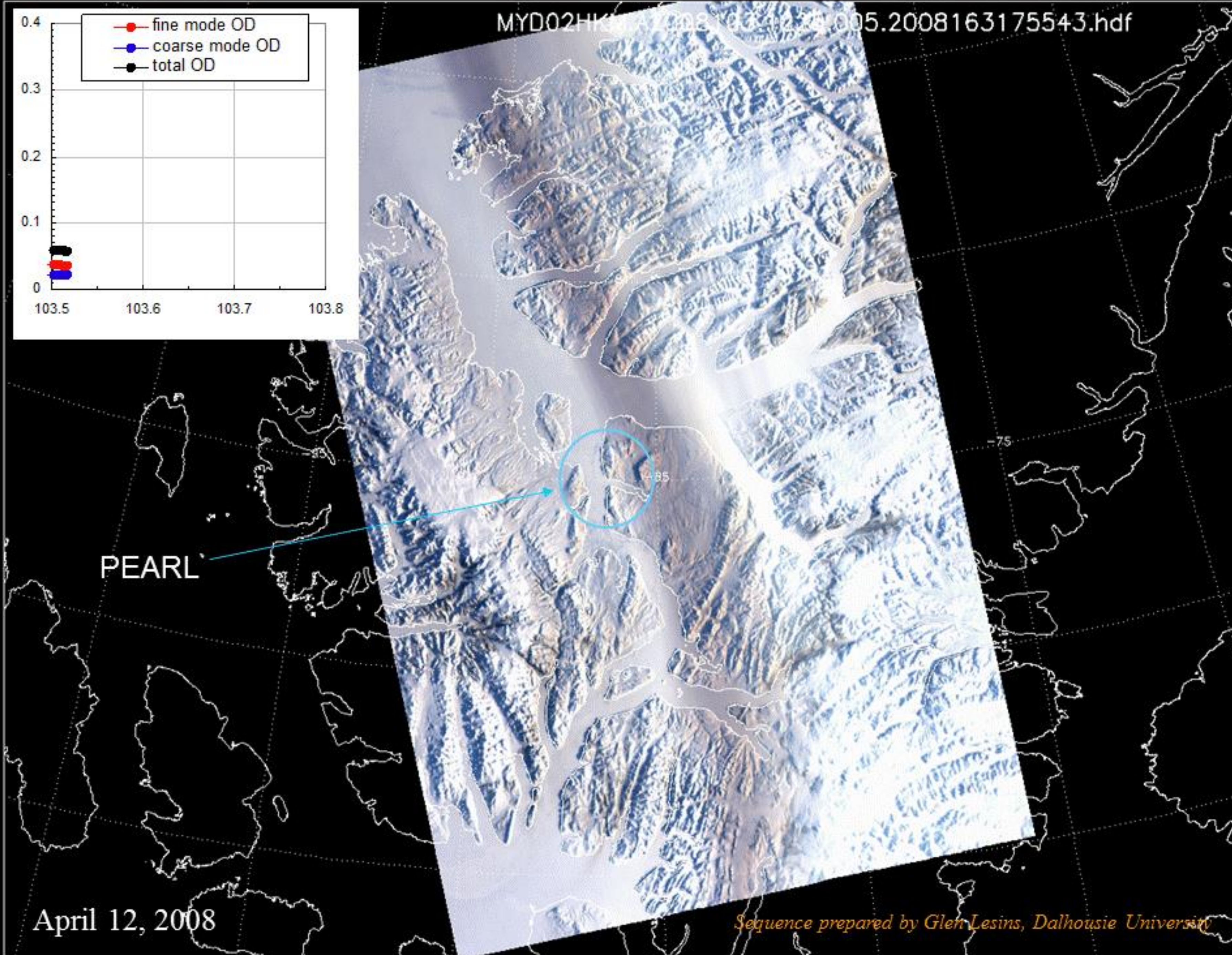


AOD_{500nm} Historical Comparisons

Years/Site	Wash. DC	Baltimore	New York City
1903-’07	0.24		
1961-’66	0.37 ±0.04	0.51 ±0.04	0.39 ±0.04
1993-’99	0.22 ±0.01	0.22 ±0.02	0.20 ±0.02
2000-’14	0.19 ±0.01	0.20 ±0.01	0.17 ±0.01

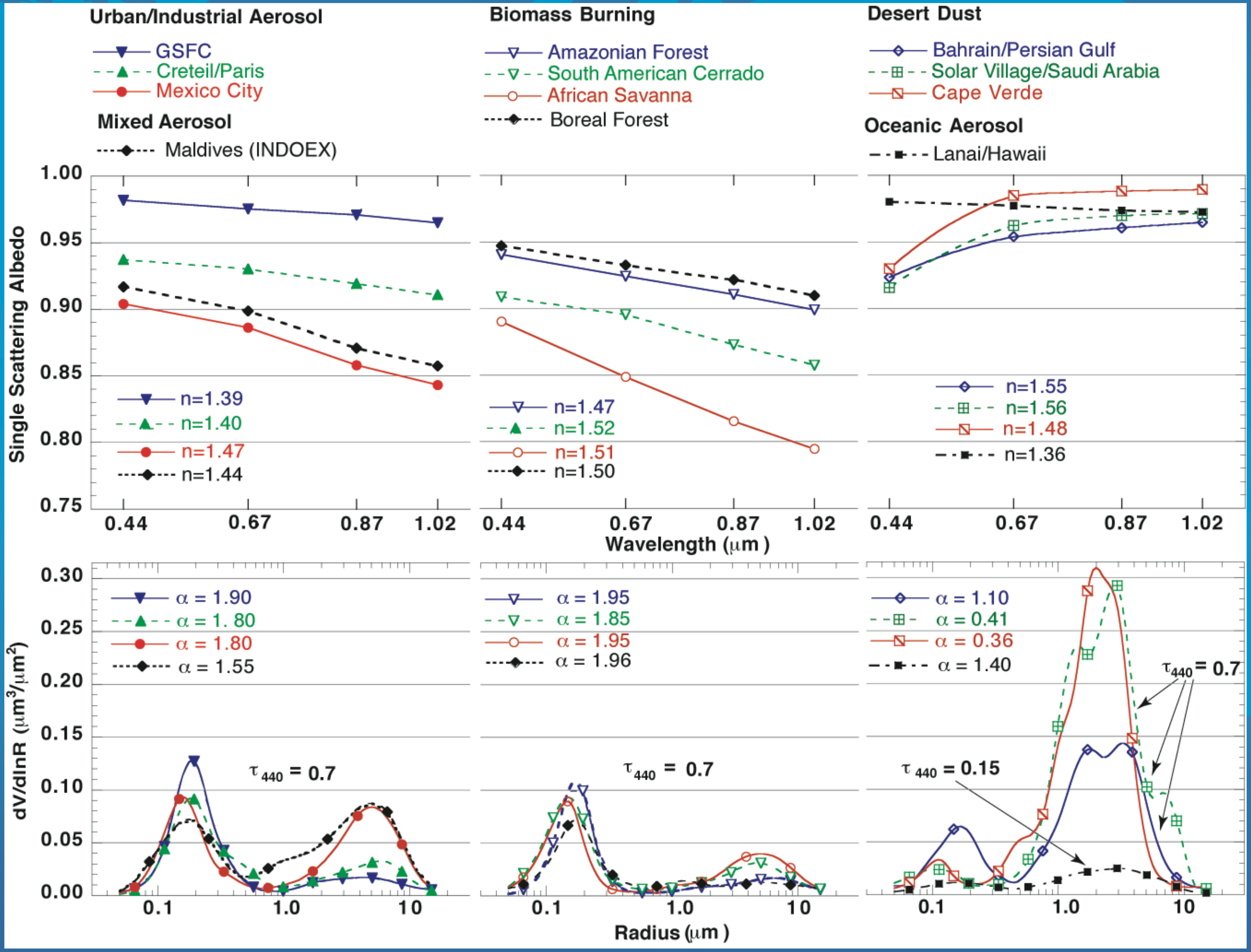


Non-linearity of ln τ_a versus ln λ is frequently observed in AERONET AOD spectra, especially for fine mode dominated size distributions; Eck et al, 1999



fine mode OD
coarse mode OD
total OD
0.4
0.3
0.2
0.1
0
103.5
103.6
103.7
103.8
PEARL
-75
April 12, 2008
Sequence prepared by Glen Lesins, Dalhousie University

Aerosol Inversion Properties Climatology from AERONET



Dubovik et al. (2002)

Field Campaigns & Sites of Opportunity

- SCAR-A (1993)/TARFOX (1996)-Urban Aerosol
- SCAR-B (1995)- Biomass Burning in Amazonia
- SAFARI2000-Biomass Burning Southern Africa
- UAE^2 (2004)-Dust
- TIGERZ-2008-present: Mixed aerosol/Monsoon
- 7-SEAS (2007-present)
- DRAGON/DISCOVER-AQ (2011-16)

Early Brasil-Biomass Burning

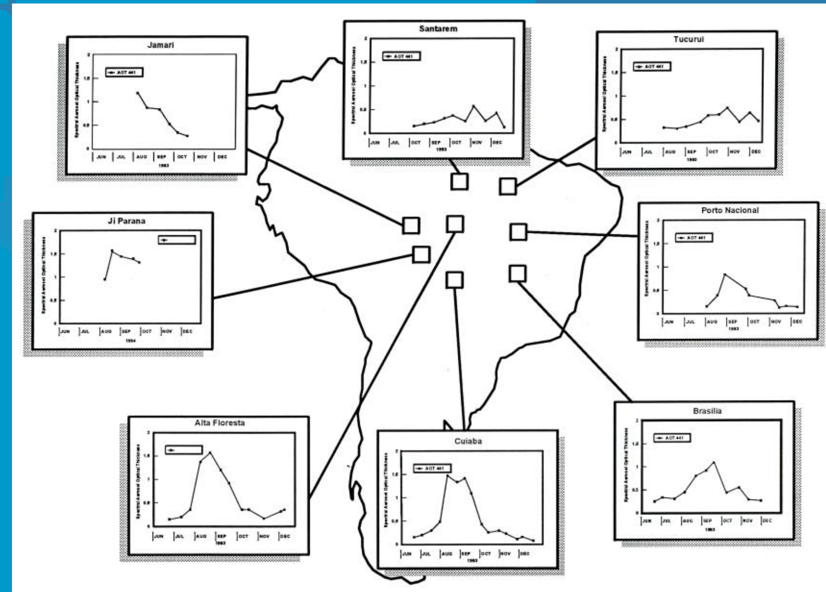


Figure 1. The aerosol optical thickness measured at 440 nm (AOT_{440}) averaged and plotted against date clearly shows the elevated levels of aerosols to be in the southern and eastern Amazon. This corresponds to the biomass burning activities in those regions.

Holben et al., 1996

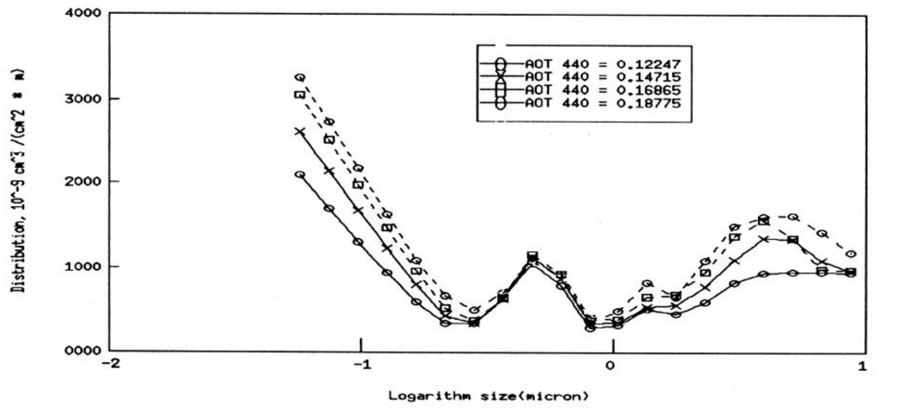
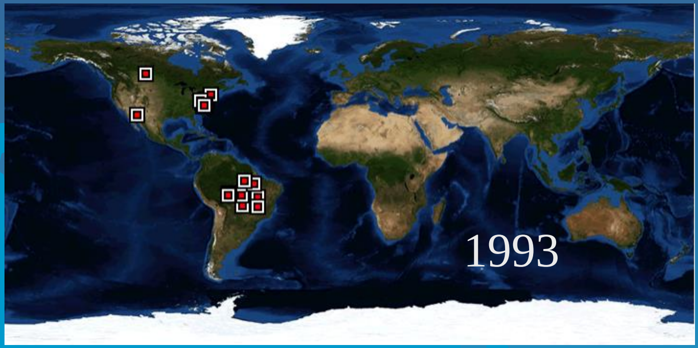


Figure 3. The size distribution during the preburning season showed a stable mode centered at 0.6 mm (Pinatubo stratospheric aerosols) and weak accumulation and coarse particle modes during 1993.



- First network in AEORNET
- First quantitative seasonal measurements of Biomass Burning aerosols in Amazon
- Described size distribution dynamics
- Identified Mt. Pinatubo middle mode and decline thru time

TARFOX (1996)-Urban Aerosol

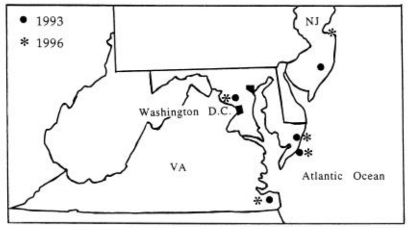
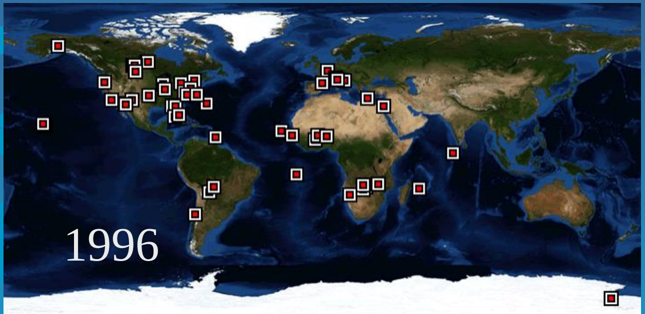
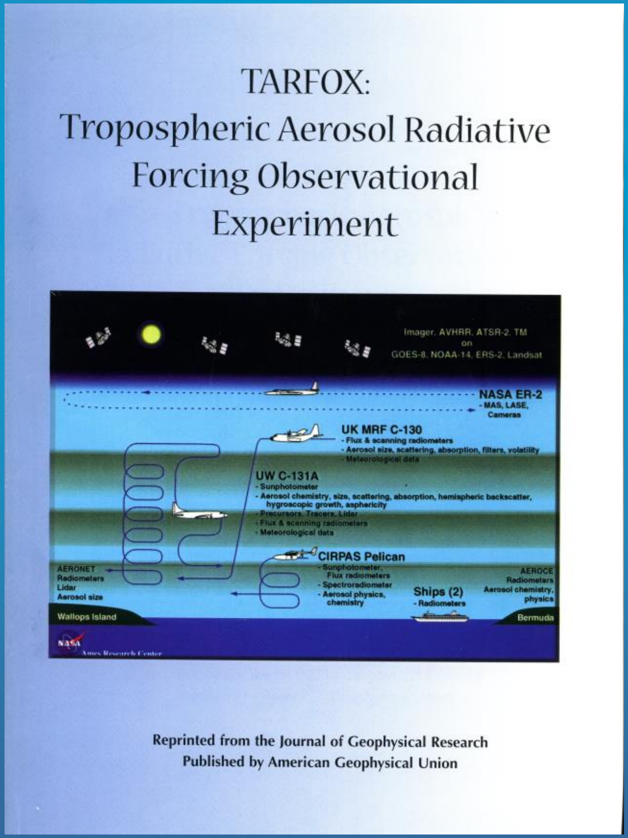


Figure 1. Sites of the AERONET Sun/sky radiometer deployment for the mid-Atlantic region in the summer of 1993 (circles) and 1996 (stars).



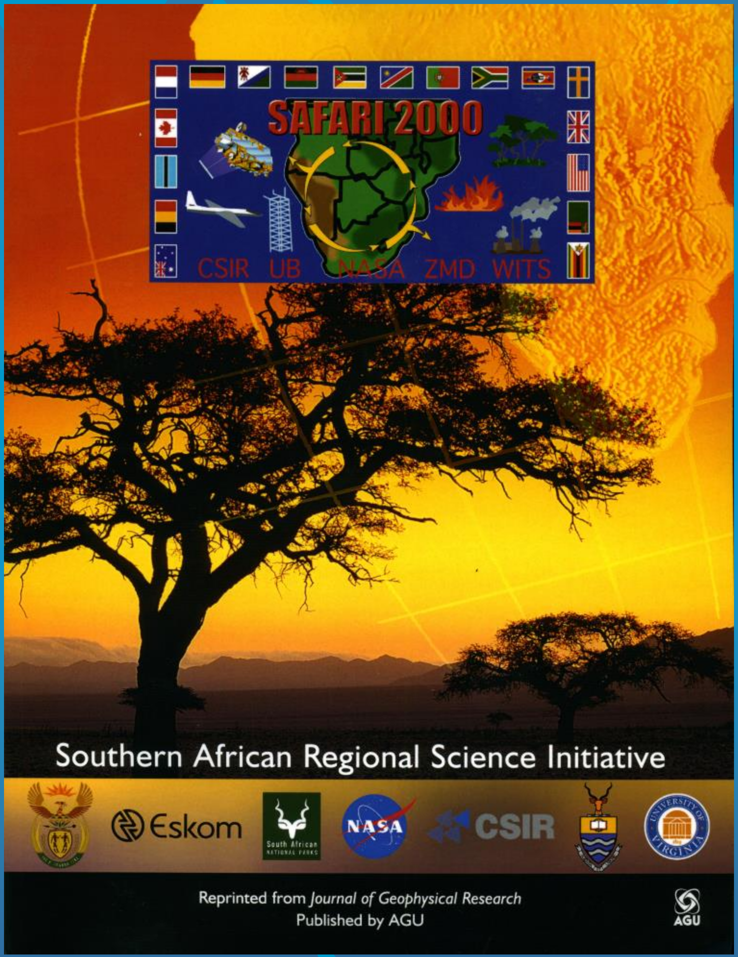


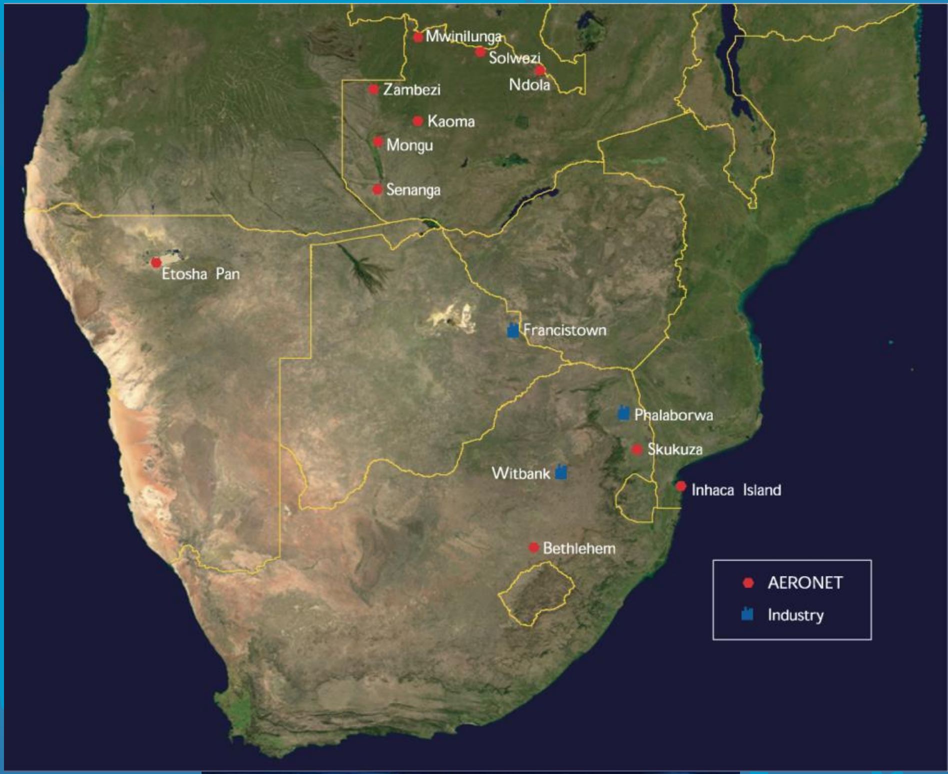
- Established urban aerosol model for high AOD (>0.20)
- Noted consistency of aerosol properties for RS and climate studies

Remer et al., 1999

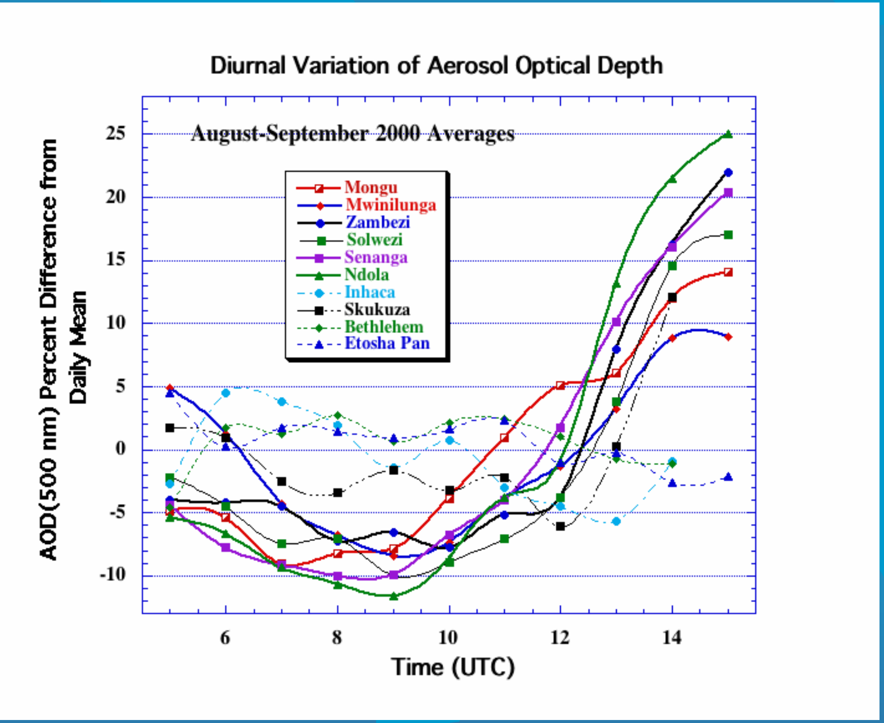
Smirnov et al, 2000

SAFARI 2000-Biomass Burning in Southern Africa





Safari2000



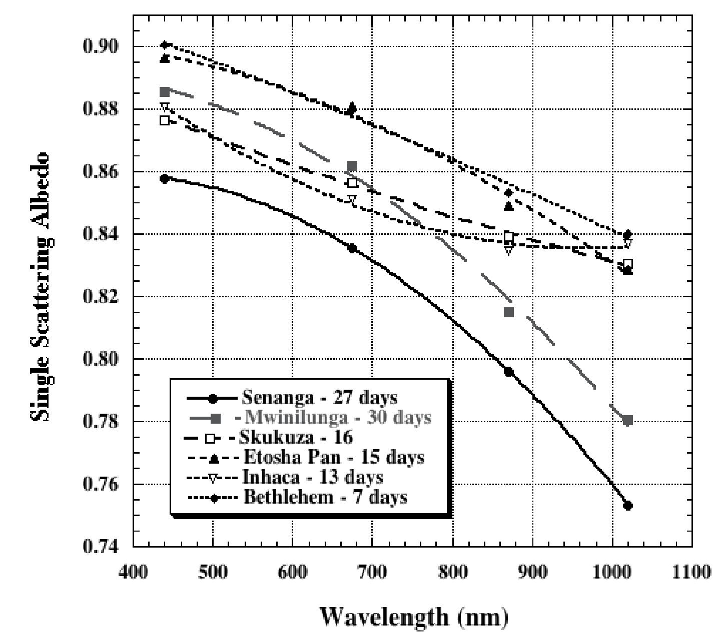


Figure 12

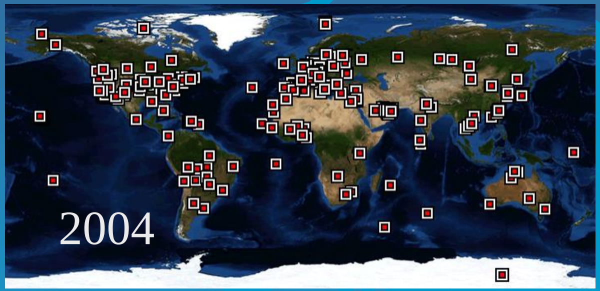
Eck et al., 2003

Additional Collaborations from Safari2000

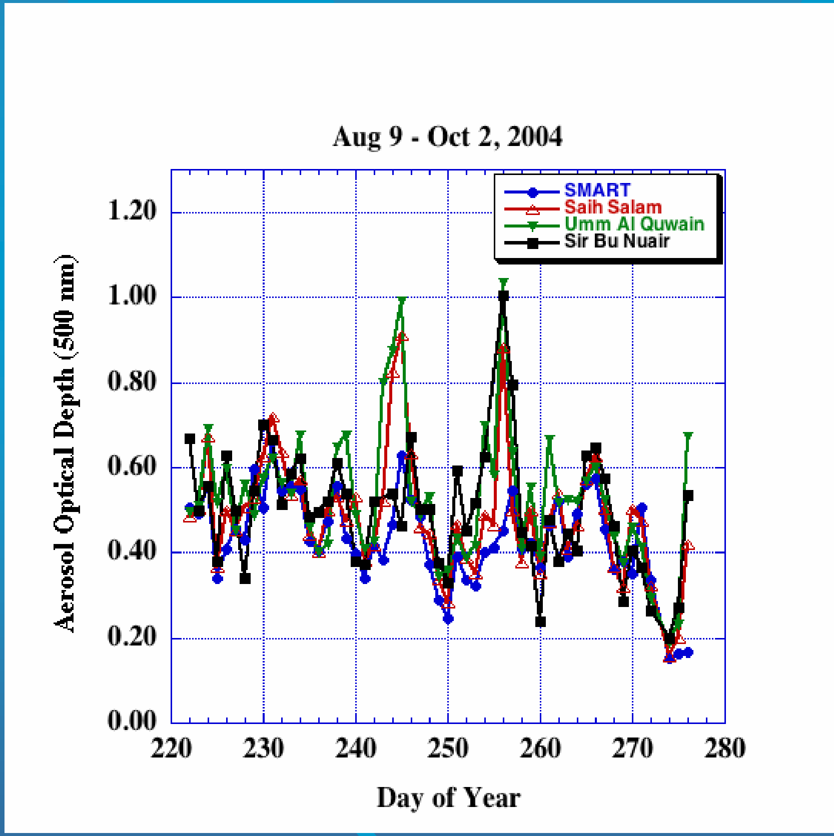
- Haywood et al., 2003
- Leahy et al., 2008
- Bergstrom et al., 2003
- Campbell et al., 2003
- Diner et al., 2002
- Ichoku et al., 2003
- Queface et al., 2003

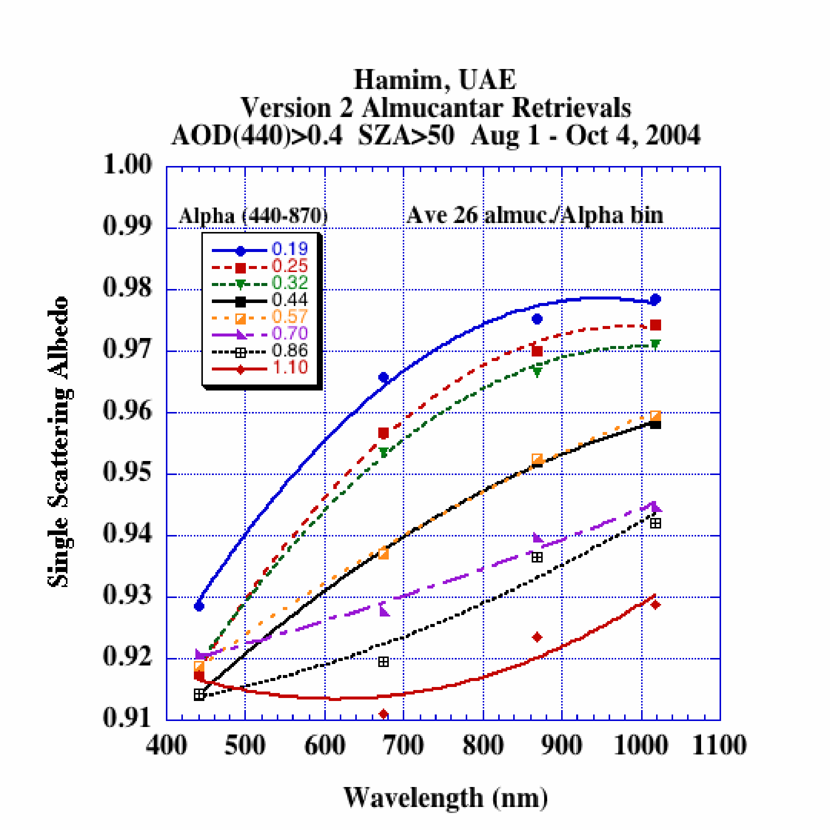
- First BB size dist. Comparison
- Comprehensive SSA comparison
- Synergism with ground-based lidar
- Radiative forcing
- Satellite Validation

UAE^2 (2004)-Dust



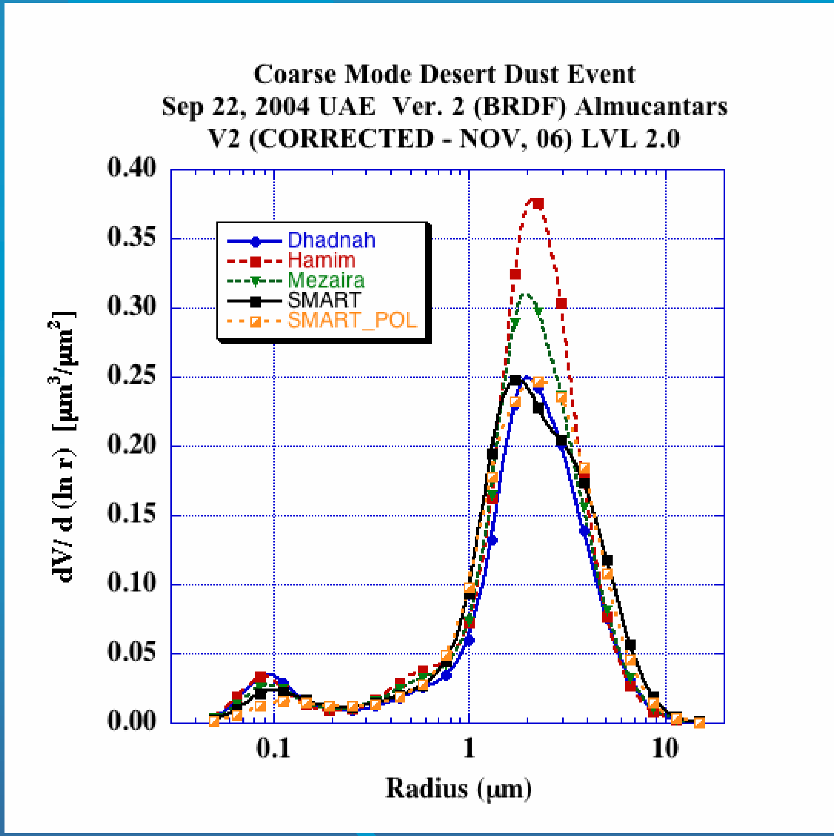
UAE^2-Properties of coarse mode aerosols

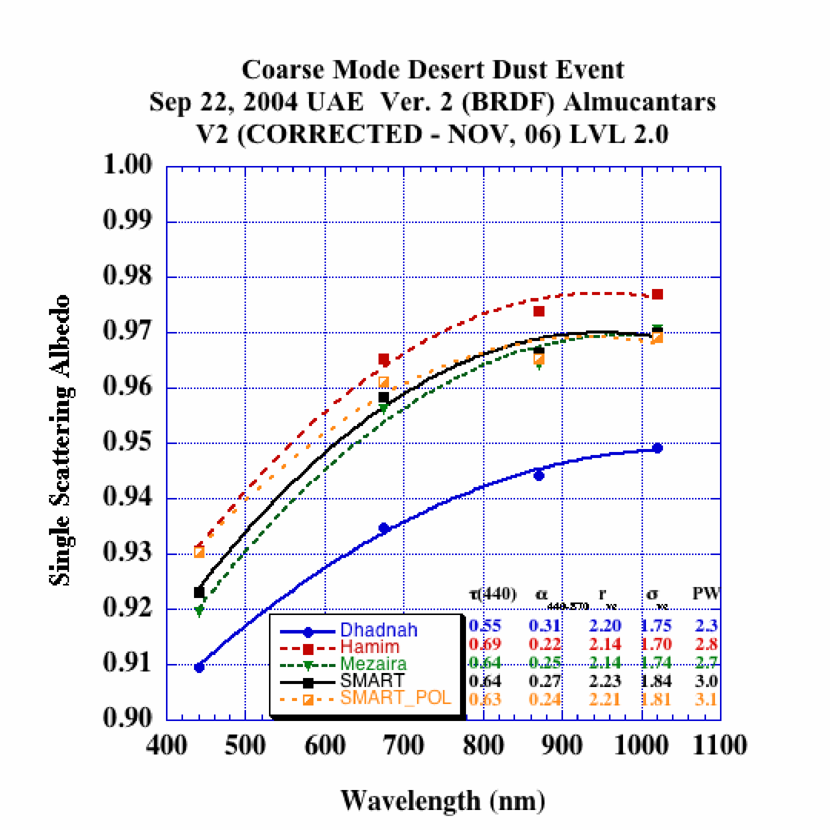




Eck et al., 2008

Properties of coarse mode event (UAE²)





Eck et al., 2008

Seven South East Asian Studies (7 SEAS)

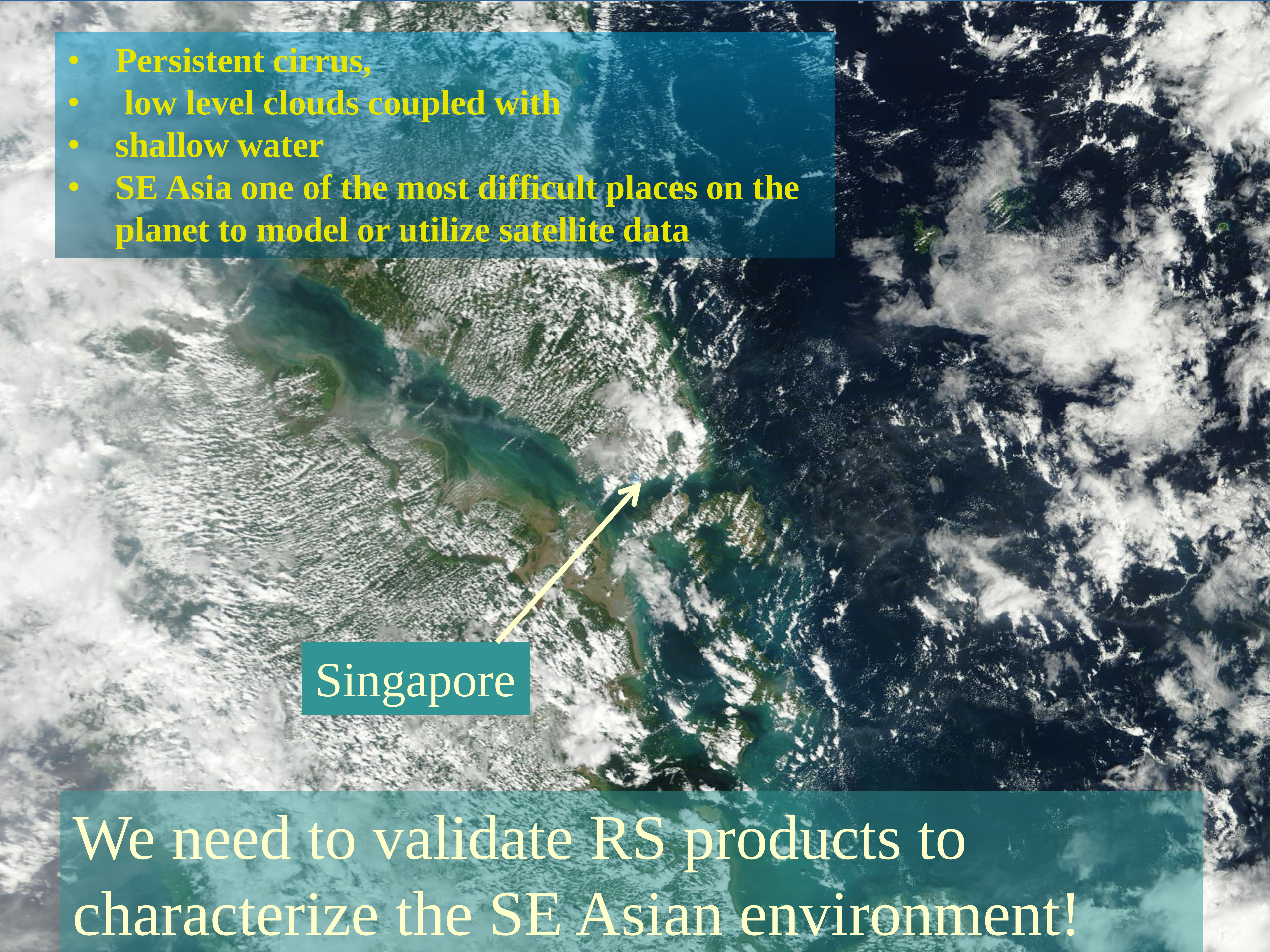
Goal: Isolate the impacts of aerosol particles on *weather and the environment*

In order to do this, we need input from seven research areas:

i

- Tropical and subtropical meteorology including air-sea and land interaction
- Clouds and precipitation
- Radiative transfer
- Biomass burning and pollution
- Natural aerosol chemistry
- Satellite and model calibration/validation
- Seasonal forecasting and climate

- **Persistent cirrus,**
- **low level clouds coupled with**
- **shallow water**
- **SE Asia one of the most difficult places on the planet to model or utilize satellite data**



We need to validate RS products to characterize the SE Asian environment!

Cirrus contamination in AERONET AOD

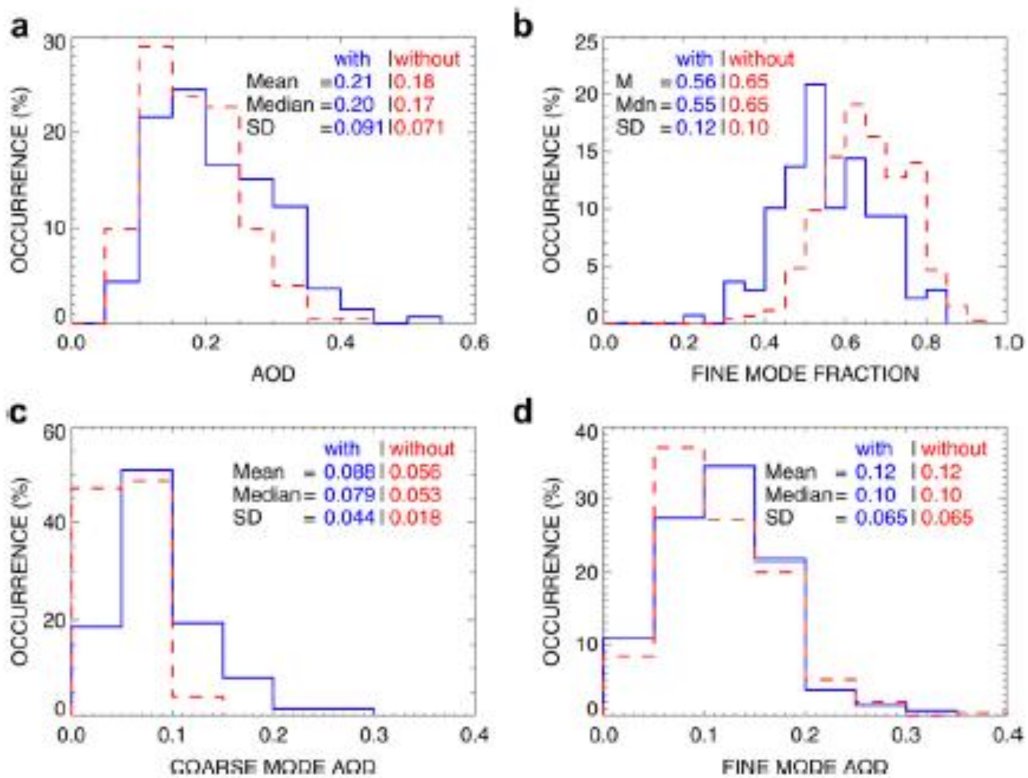


Fig. 4. Sample sizes for AERONET Level 2.0 observations with (blue solid) and without cirrus contamination (red dashed) are 139 and 455 respectively. The bin sizes for all panels are 0.05. (a) Distributions for AOD, (b) fine mode fraction, (c) coarse mode AOD and (d) fine mode AOD at 0.500 μm. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

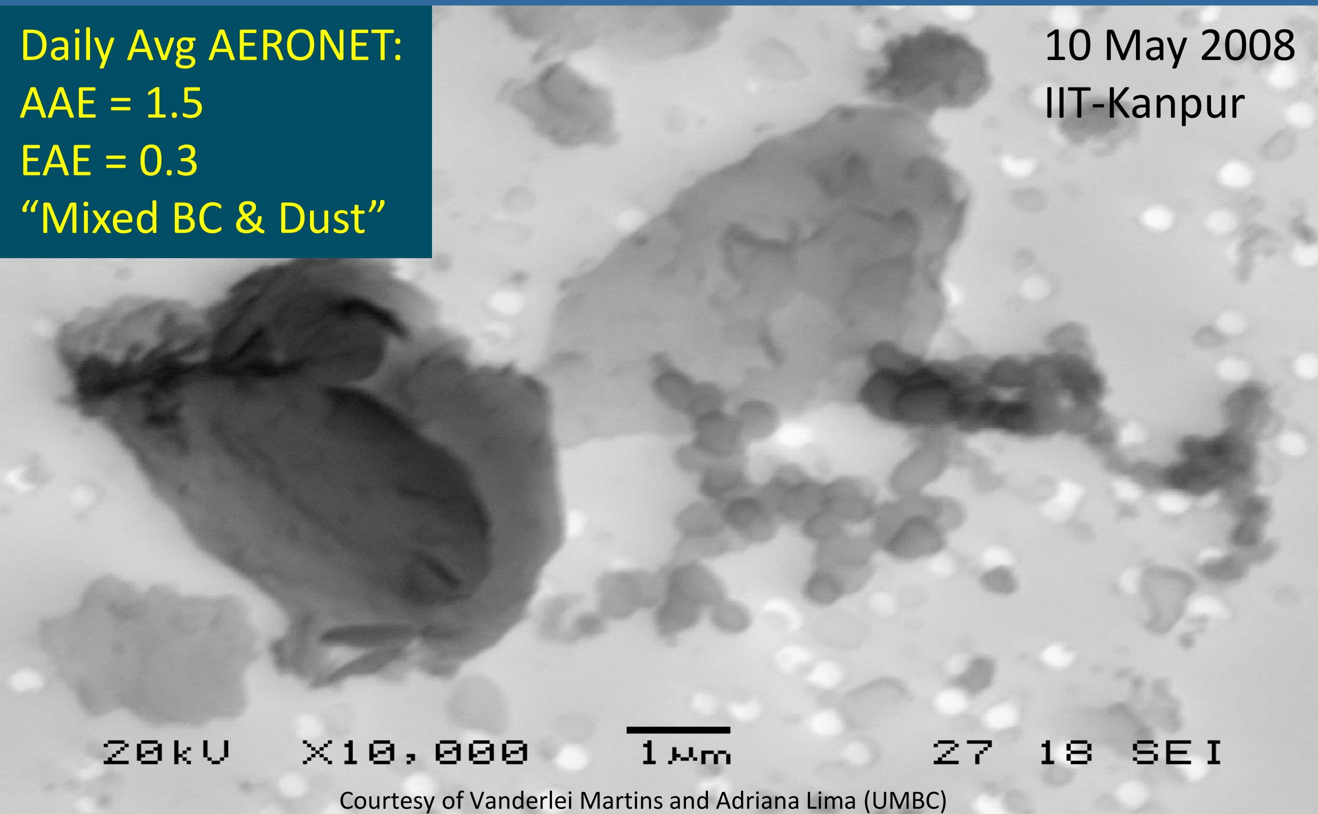
TIGERZ-2008: Mixed Aerosol Pre Monsoon

Space shuttle view of IGP

Black Carbon source

Dust and Black Carbon Particles

Daily Avg AERONET:
AAE = 1.5
EAE = 0.3
“Mixed BC & Dust”

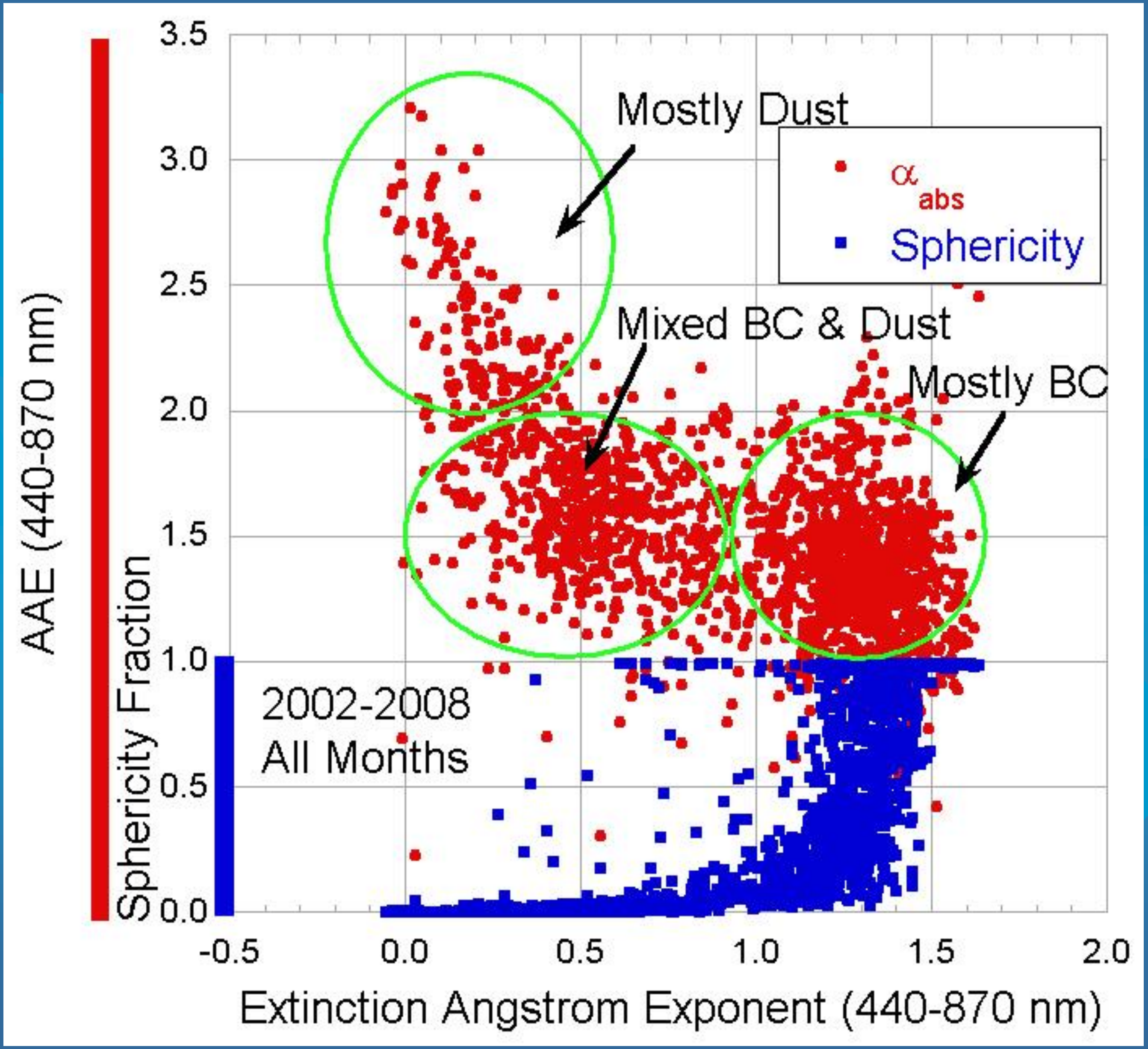


Courtesy of Vanderlei Martins and Adriana Lima (UMBC)

Courtesy of Sheng-Hsiang Wang

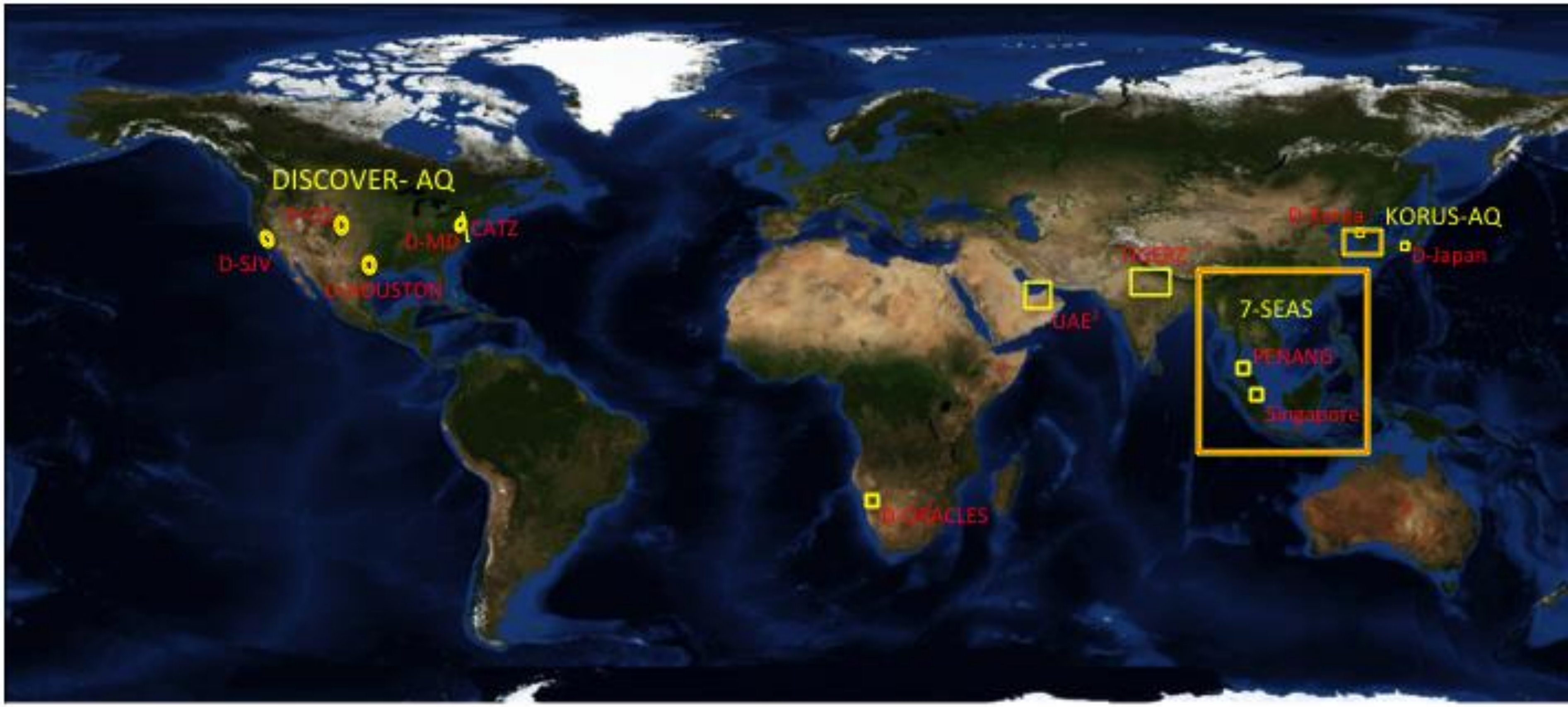
Courtesy of Sheng-Hsiang Wang

Dominant Absorbing Aerosols over Kanpur



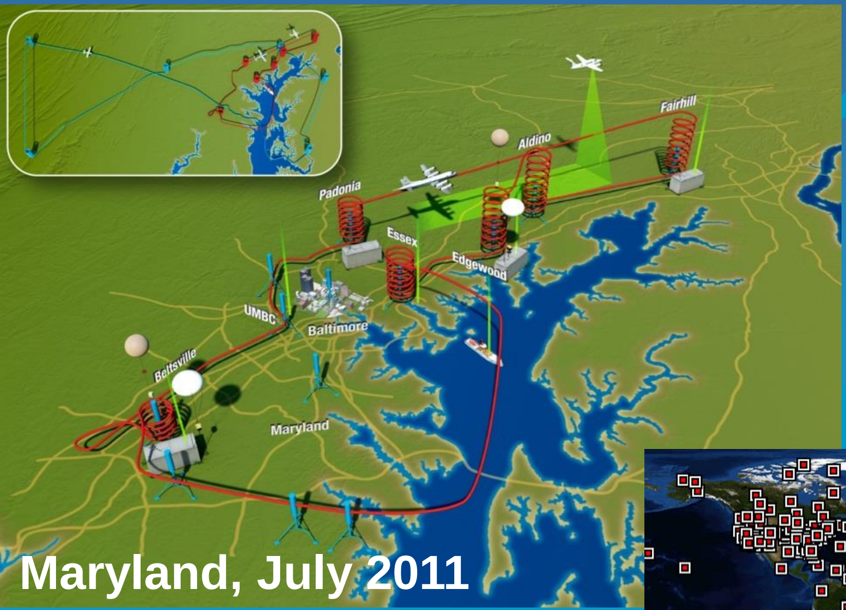
From Giles et al. [2011]

Distributed Regional Aerosol Gridded Observation Network (DRAGON)



The DRAGON Campaigns 2011 to present

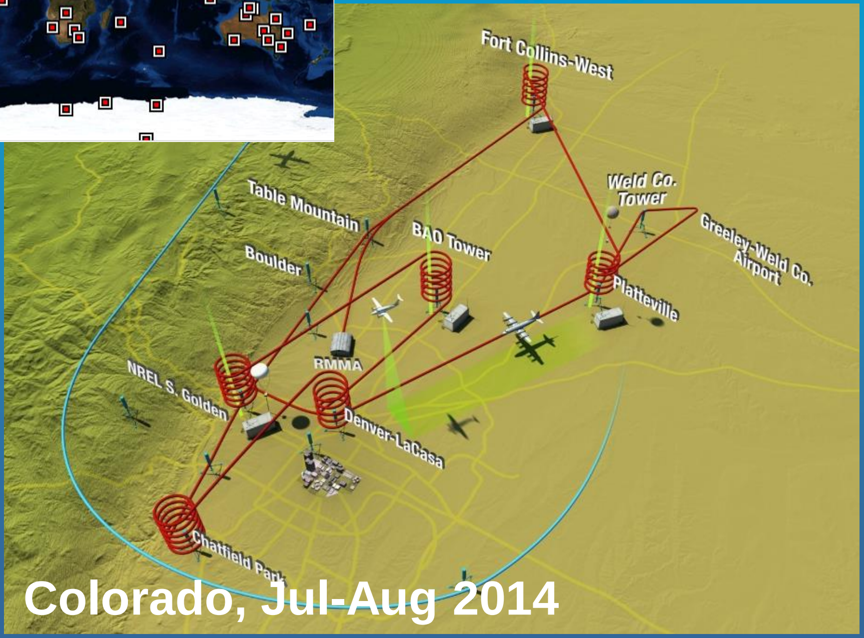
Discover AQ: Deployment Locations



Maryland, July 2011

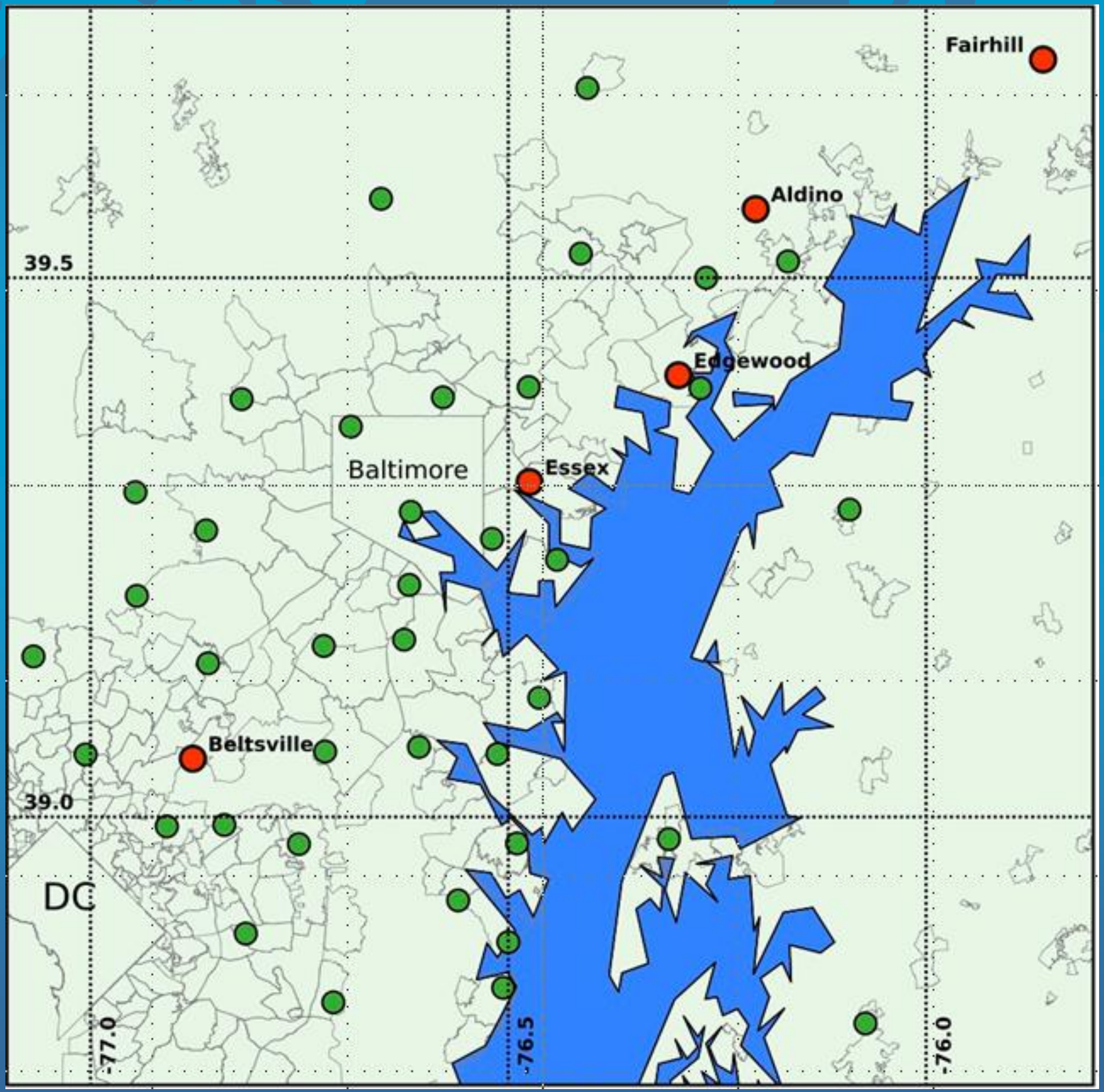
Houston, September 2013

California, Jan-Feb 2013

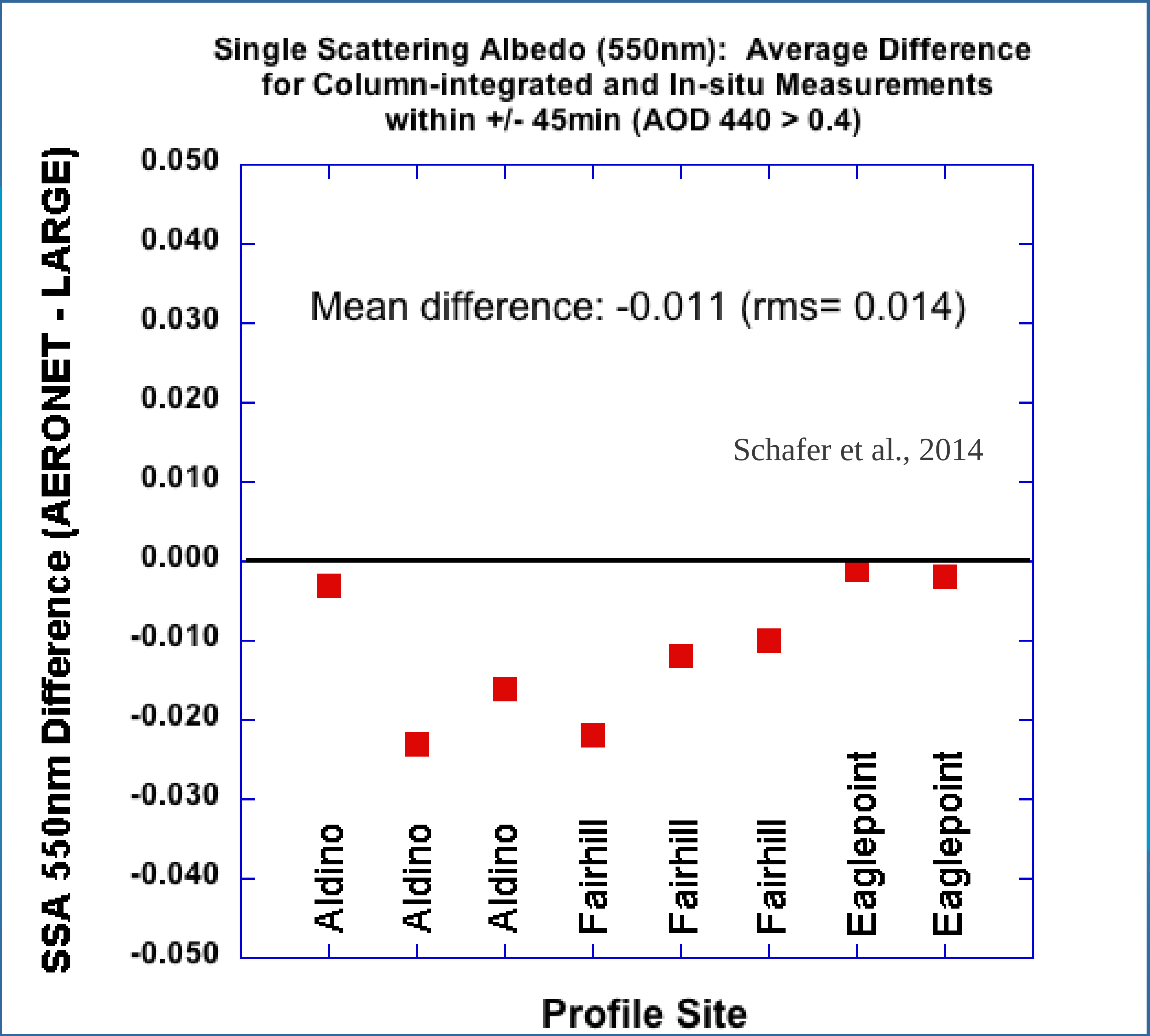


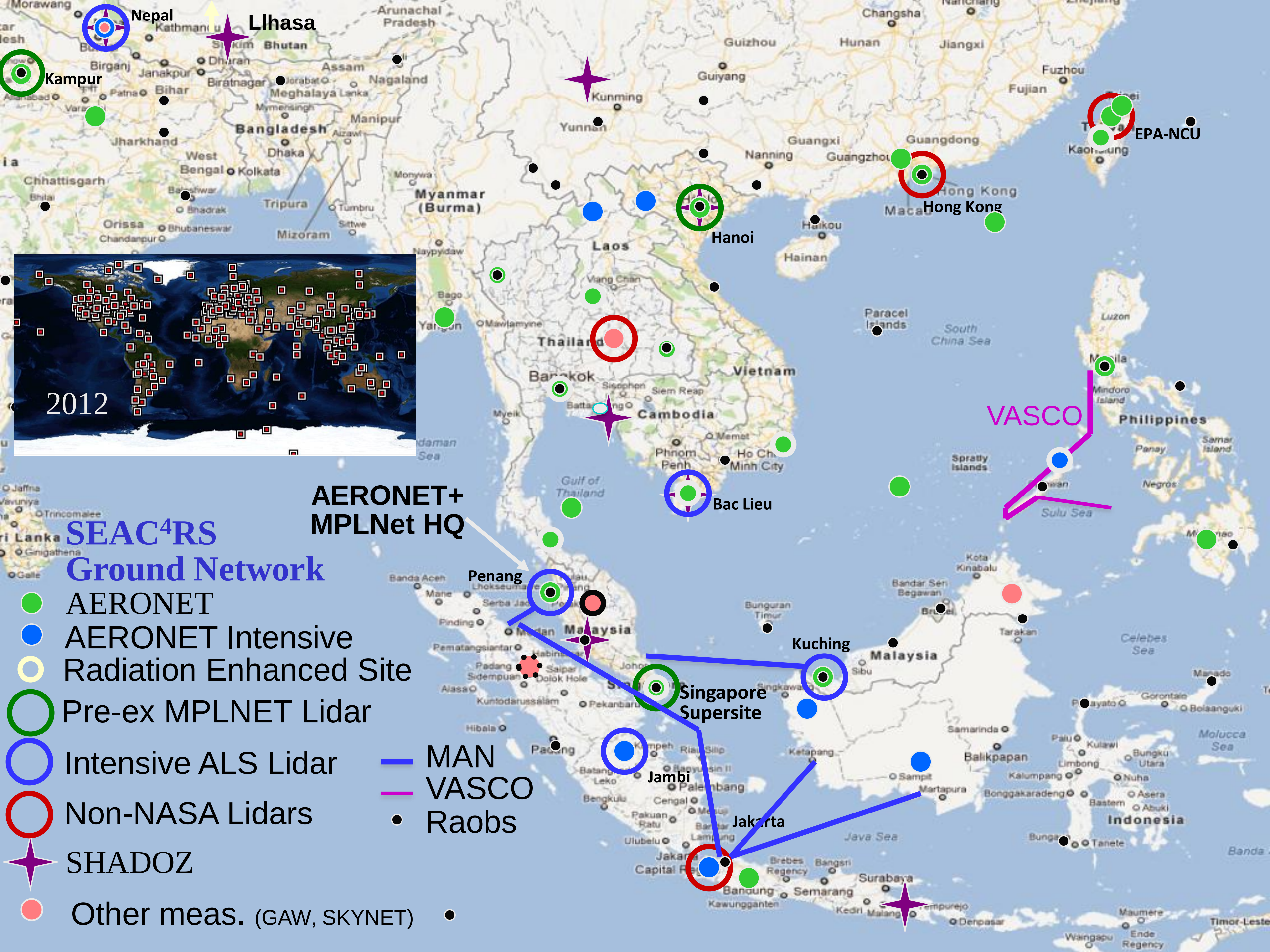
Colorado, Jul-Aug 2014

Distributed Regional Aerosol Gridded Observation Network, DRAGON



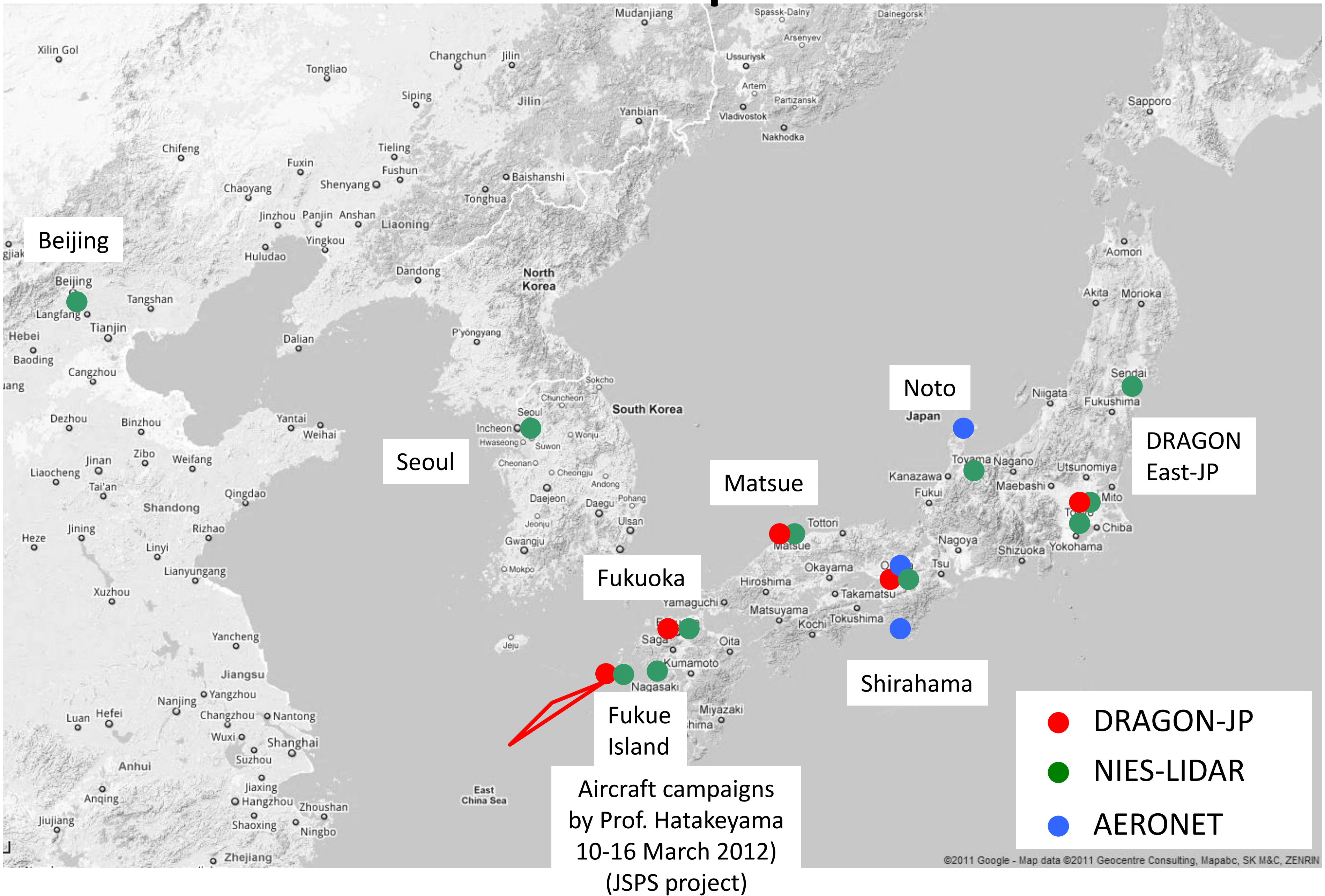
44 AERONET sites
I-95 Corridor: Urban to Suburban to Rural to water
~50 x 100 km
May 15 to Aug. 19


Single Scattering Albedo (550nm): Average Difference
for Column-integrated and In-situ Measurements
within +/- 45min (AOD 440 > 0.4)
SSA 550nm Difference (AERONET - LARGE)
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
Mean difference: -0.011 (rms= 0.014)
Schafer et al., 2014
Aldino
Aldino
Aldino
Fairhill
Fairhill
Fairhill
Eaglepoint
Eaglepoint
Profile Site


SEAC4RS Ground Network
AERONET
AERONET Intensive
Radiation Enhanced Site
Pre-ex MPLNET Lidar
Intensive ALS Lidar
Non-NASA Lidars
SHADOZ
Other meas. (GAW, SKYNET)
MAN
VASCO
Raobs
AERONET+ MPLNet HQ
2012
Nepal
Llhasa
Kampur
Hanoi
Hong Kong
EPA-NCU
VASCO
Bac Lieu
Penang
Kuching
Singapore Supersite
Jambi
Jakarta

Deployment plan of AERONET instruments during DRAGON JP

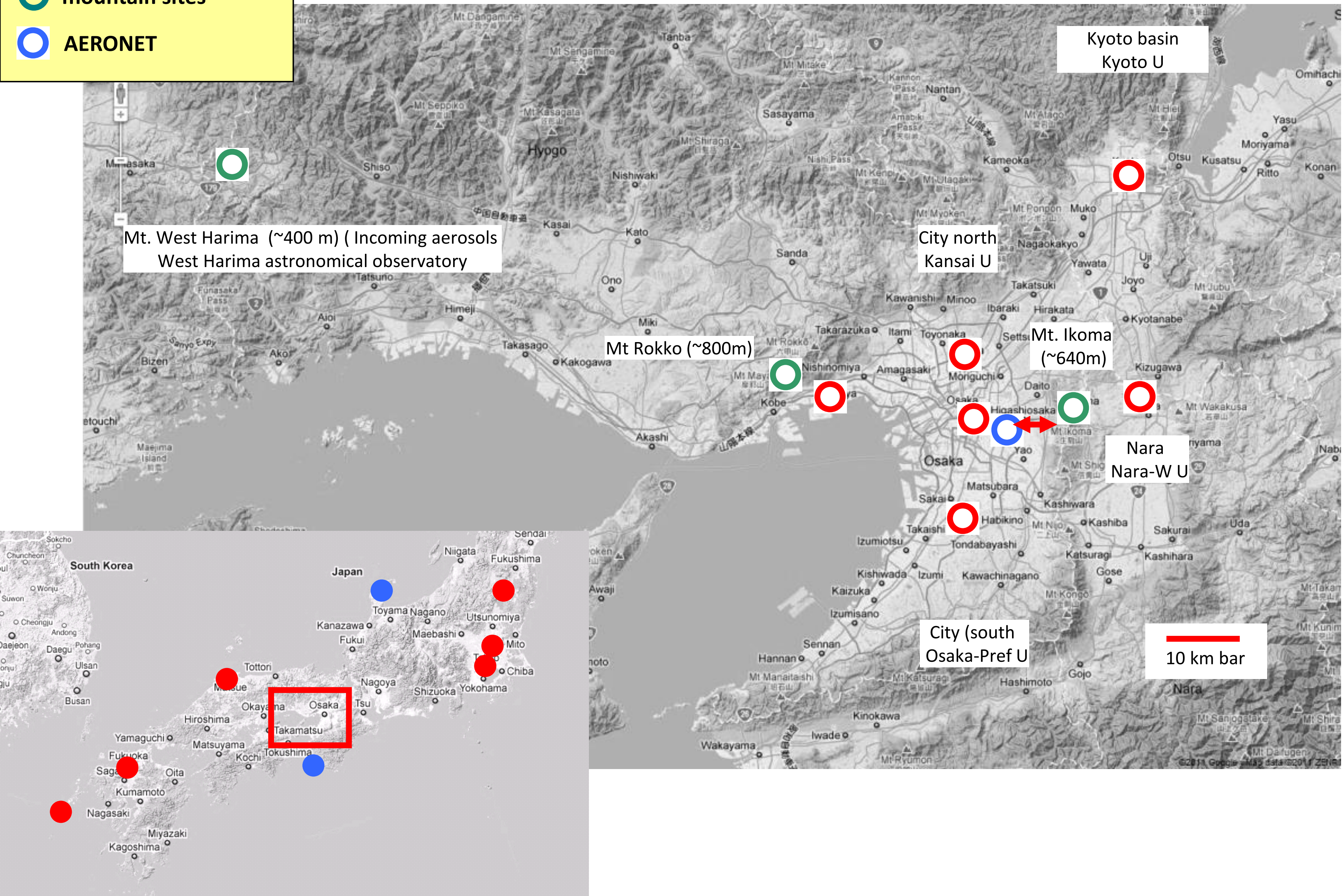
DRAGON Japan 2012



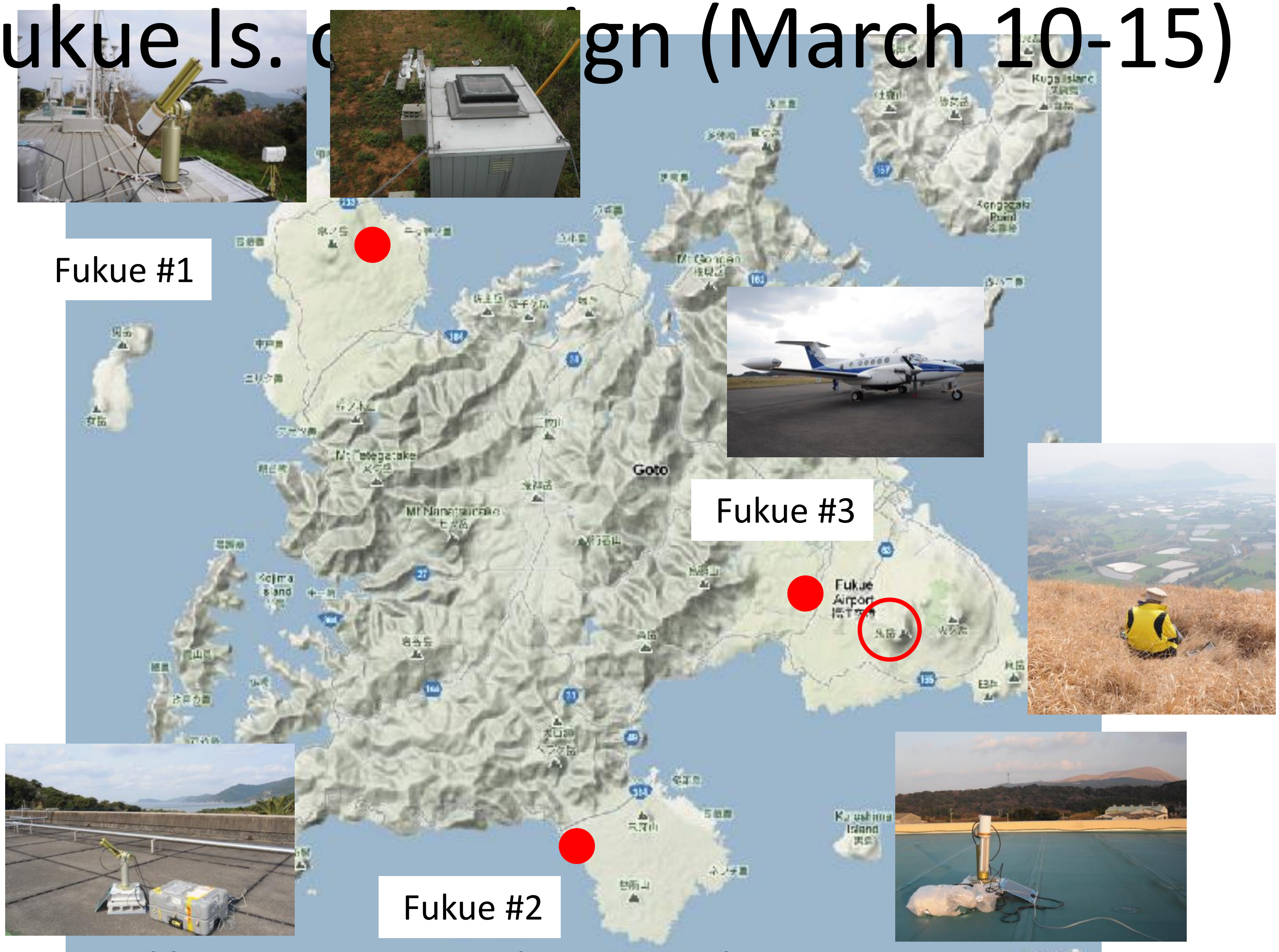
DRAGON - Osaka

Expected candidate sites

- city sites
- mountain sites
- AERONET



Fukue Is. c gn (March 10-15)



http://www.tuat.ac.jp/~aerosol/data_entrance.html

Objectives

DRAGON-Japan (-West-JP, -Osaka) campaign focuses on investigating the following topics :

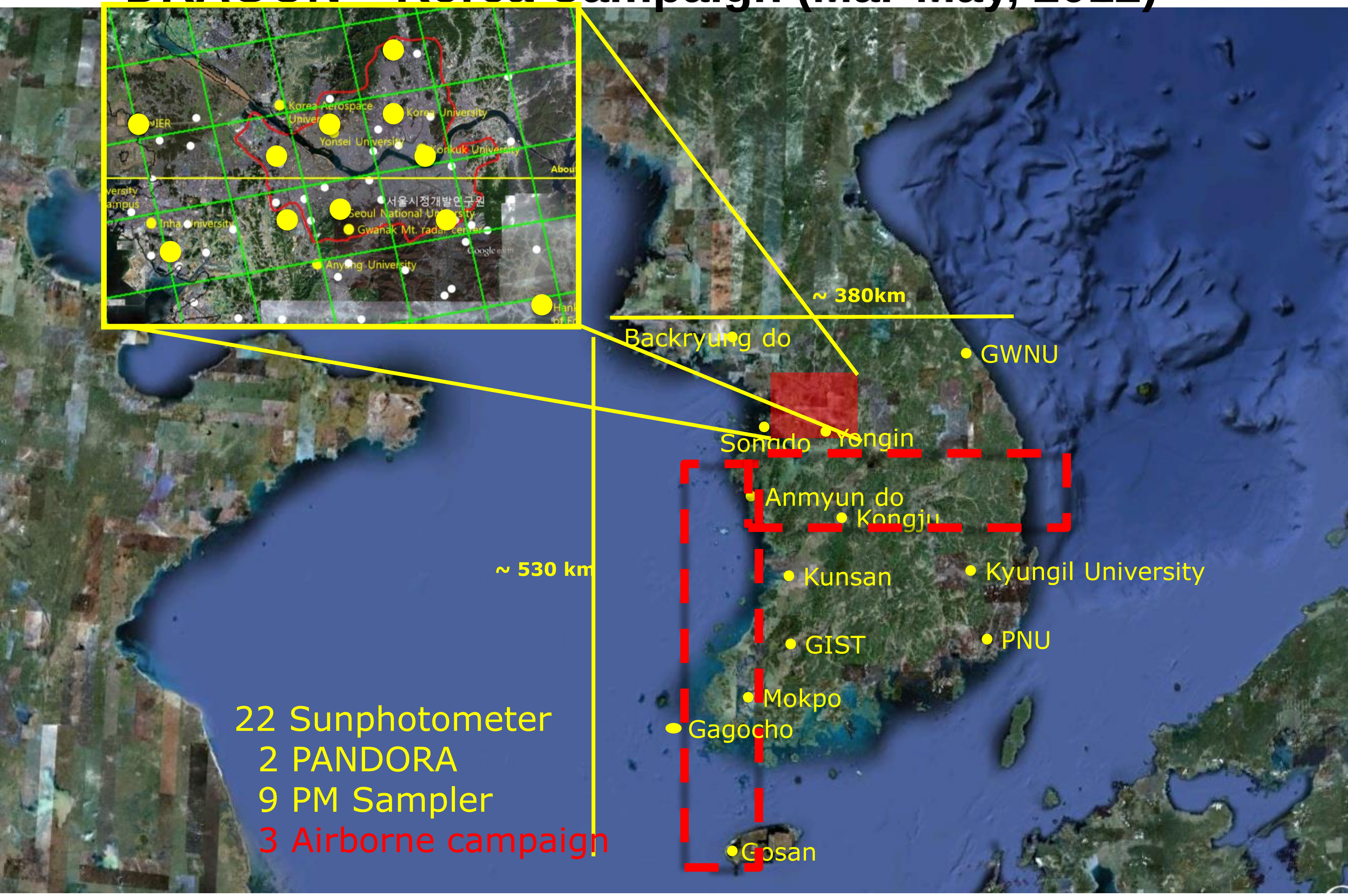
1. Long range trans boundary aerosols from continent
   i.e., anthropogenic aerosols and Asian dusts
   - **DRAGON West-JP** and **AERONET JP sites**.
   - **Aircraft measurements** over **East China Sea** (March 10-16)

     planned by Prof. Hatakeyama group

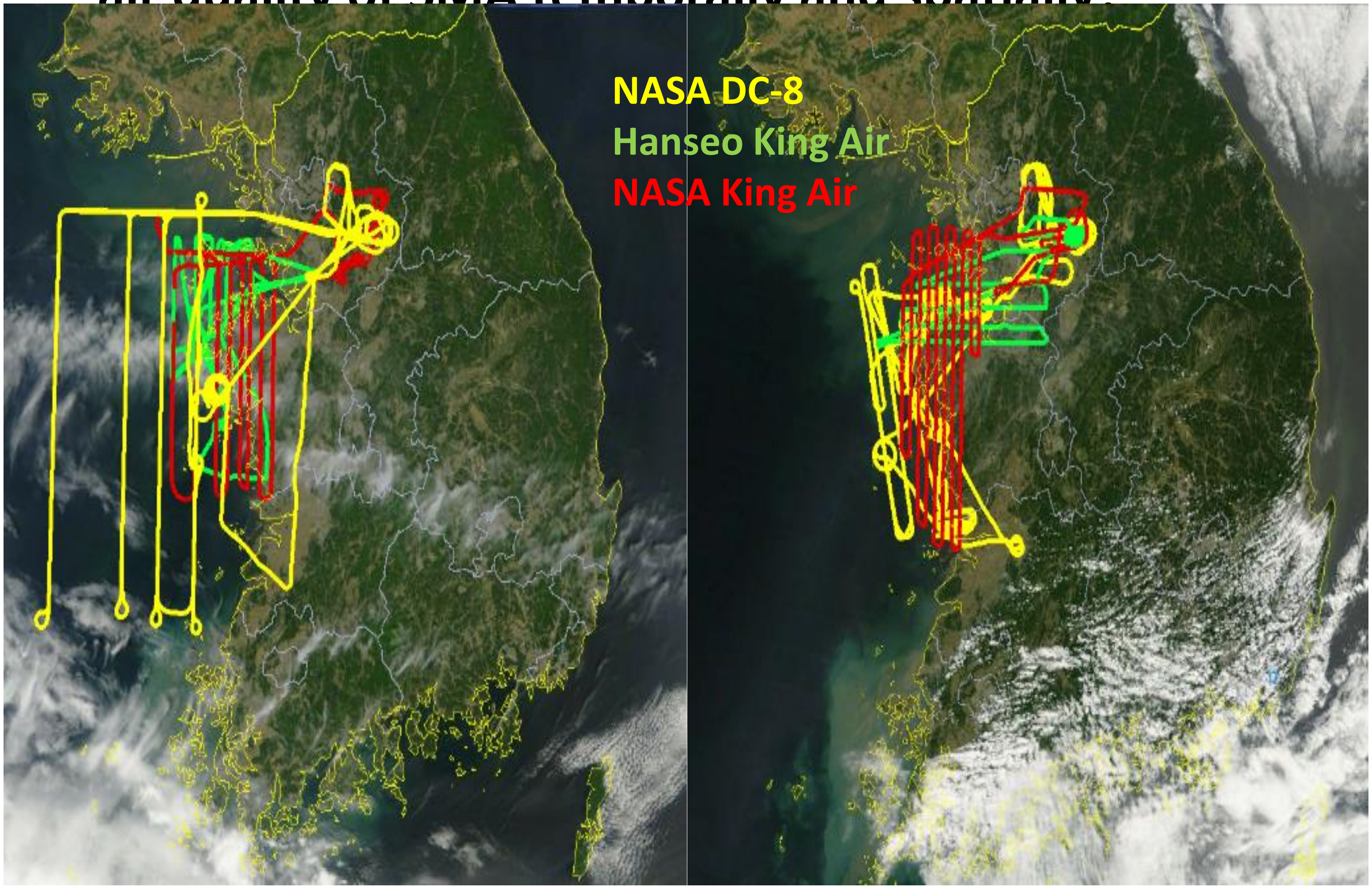
2. Regional aerosol properties over mega city
   - **DRAGON Osaka**, and in-situ data

3. Validation data for satellite measurements
   - **DRAGON Osaka**, and in-situ data

DRAGON – Korea Campaign (Mar-May, 2012)

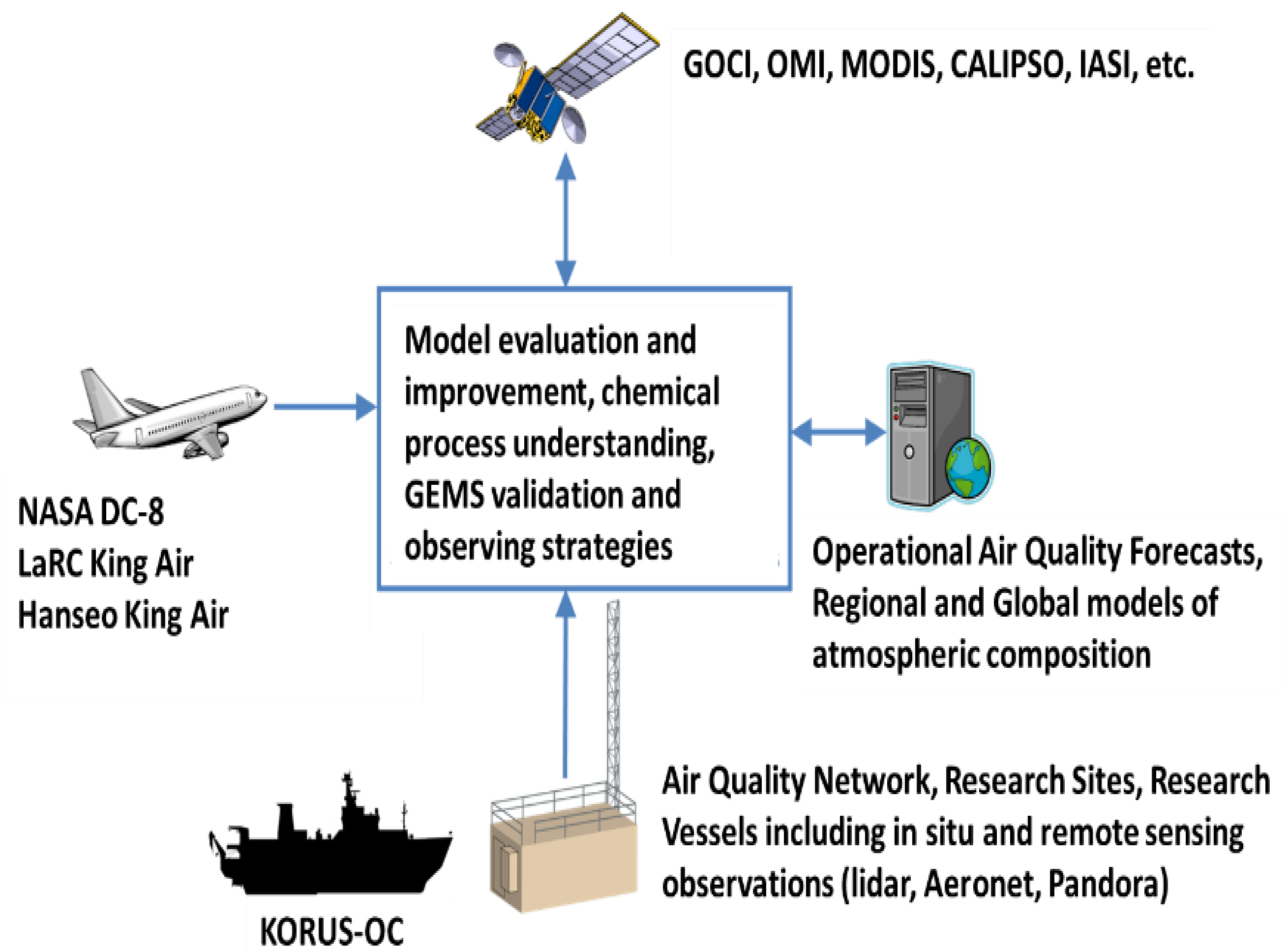


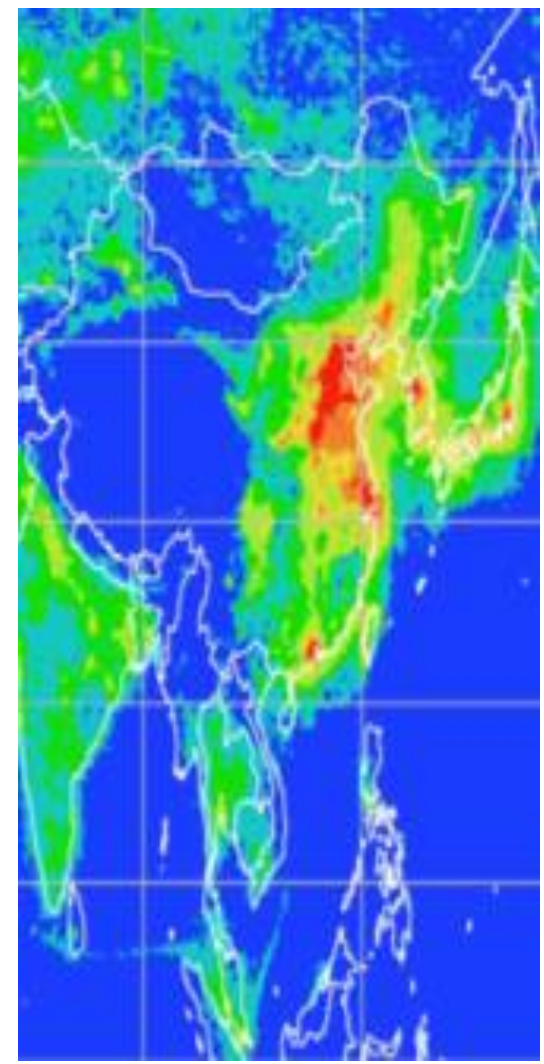
Question 1: How significant is the impact of the large point sources (power plants and petrochemical plants) along the west coast to the air quality of SMA temporally and spatially?



Coordinated airborne sampling of point sources on 22 May and 5 June du

KORUS-AQ serves as preparation for the launch of GEMS and the full implementation of an integrated observing strategy for Air Quality.





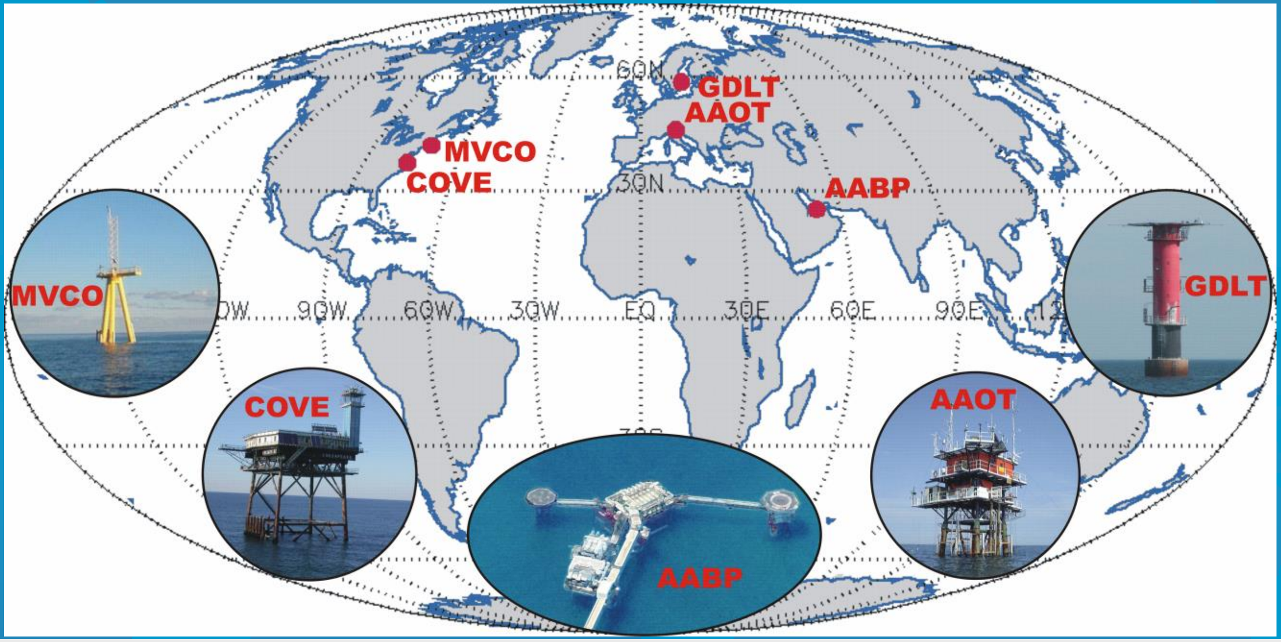
Users of AERONET data

- Oceans community
- Land surface community
- Satellite Community (AOD validation)
- Aerosol Modeling community (validation/assimilation)
- Air Quality Community
- Universities/Students/Outreach

AERONET-OC

Joint Research Centre

AERONET – Ocean Color is a sub-network of the Aerosol Robotic Network (AERONET), relying on modified sun-photometers to support ocean color validation activities with highly consistent time-series of $L_{WN}(\lambda)$ and $\tau_a(\lambda)$.



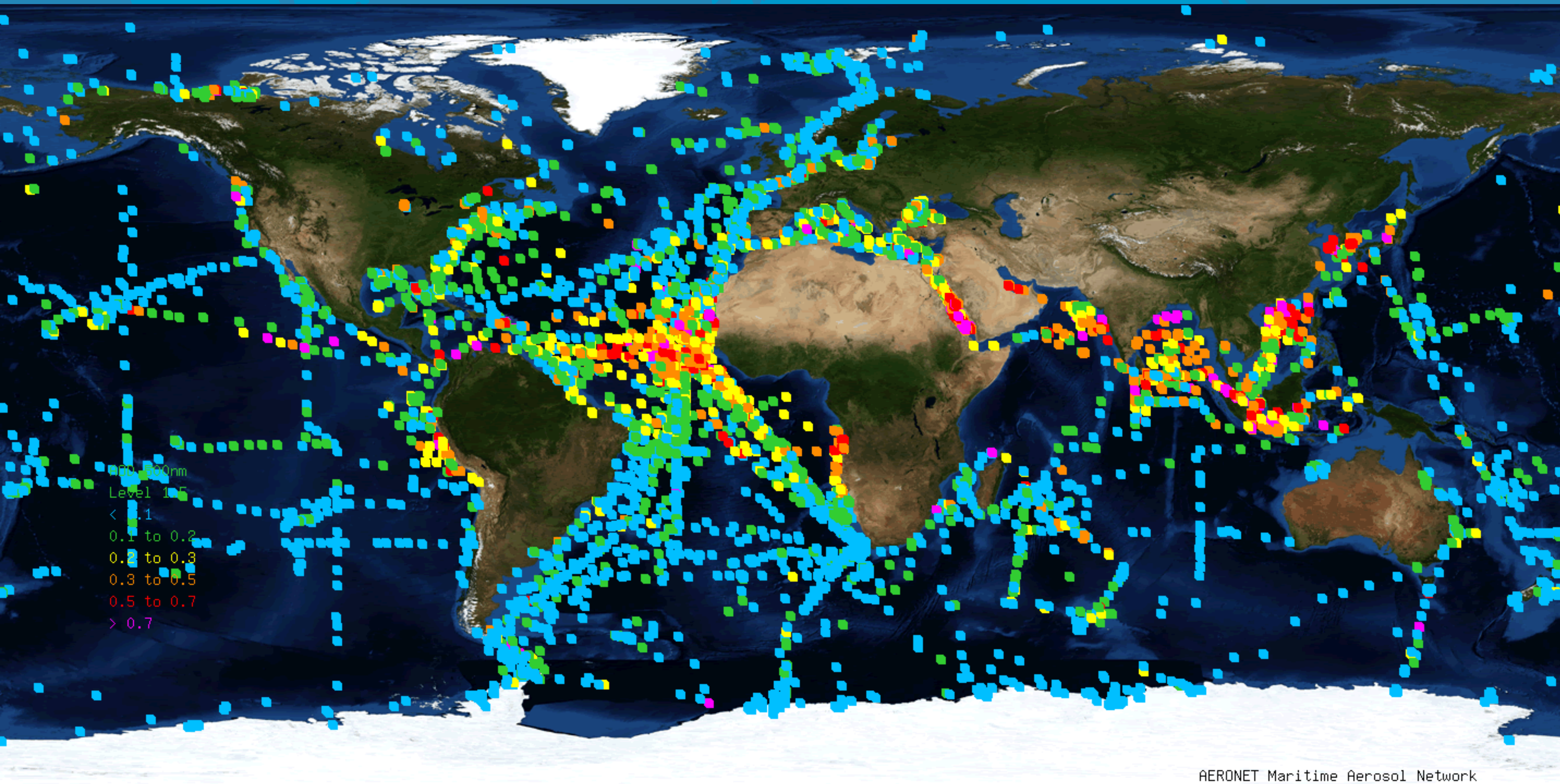
- Autonomous radiometers operated on fixed platforms in coastal regions;
- Identical measuring systems and protocols, sensors calibrated using a single reference source and method, and data processed with the same code;
- Standardized products of normalized water-leaving radiance and aerosol optical thickness.

G.Zibordi et al. A Network for Standardized Ocean Color Validation Measurements. Eos Transactions, 87: 293, 297, 2006.

Maritime Aerosol Network as a Component of AERONET

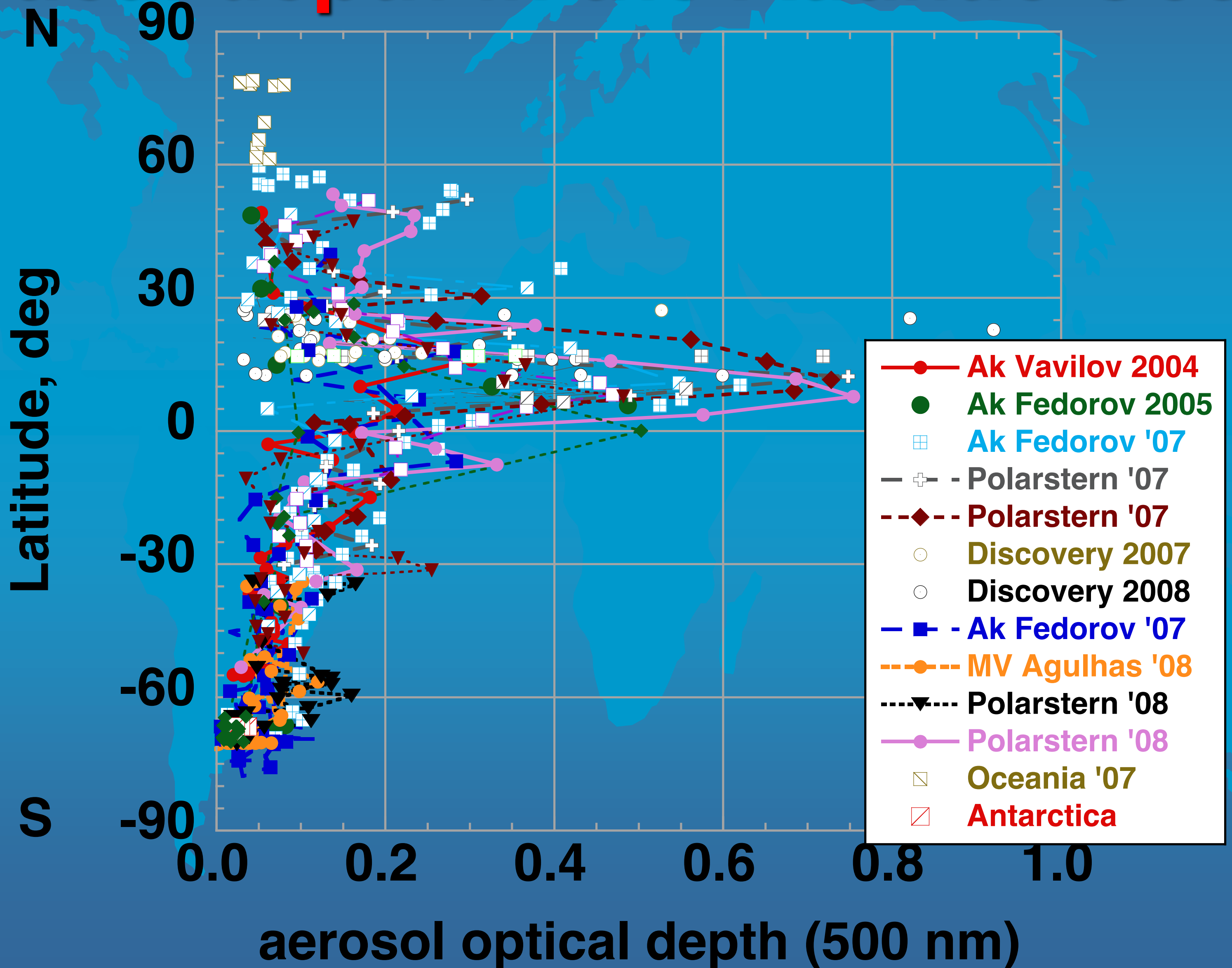
MAN represents an important strategic sampling initiative and ship-borne data acquisition complements island-based AERONET measurements

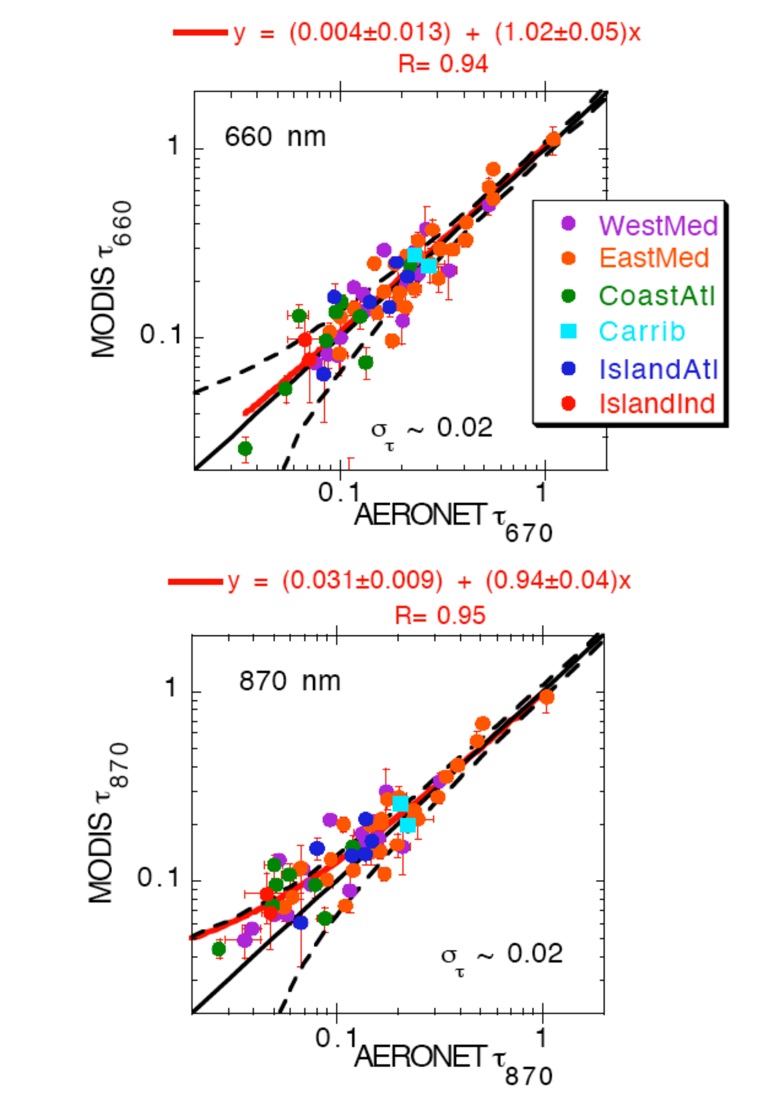
Maritime Aerosol Network global coverage from October 2006 to December 2016



Smirnov, A., et al., Maritime Aerosol Network as a component of Aerosol Robotic Network, J. Geophys. Res., 114, D06204, 2009.

Latitudinal dependence of aerosol optical depth in the Atlantic Ocean



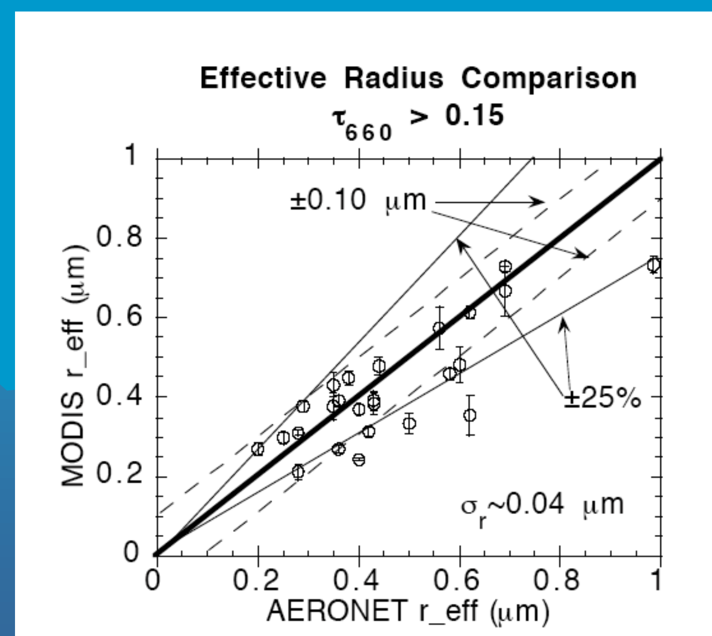


First ever MODIS validation using AERONET data.
These are for the over ocean product.

After 2 months, 64 collocated AOD data points and 25 collocated inversions when AOD > 0.15.

Data collection during the period Aug 21, 2000 to roughly Oct 20, 2000.

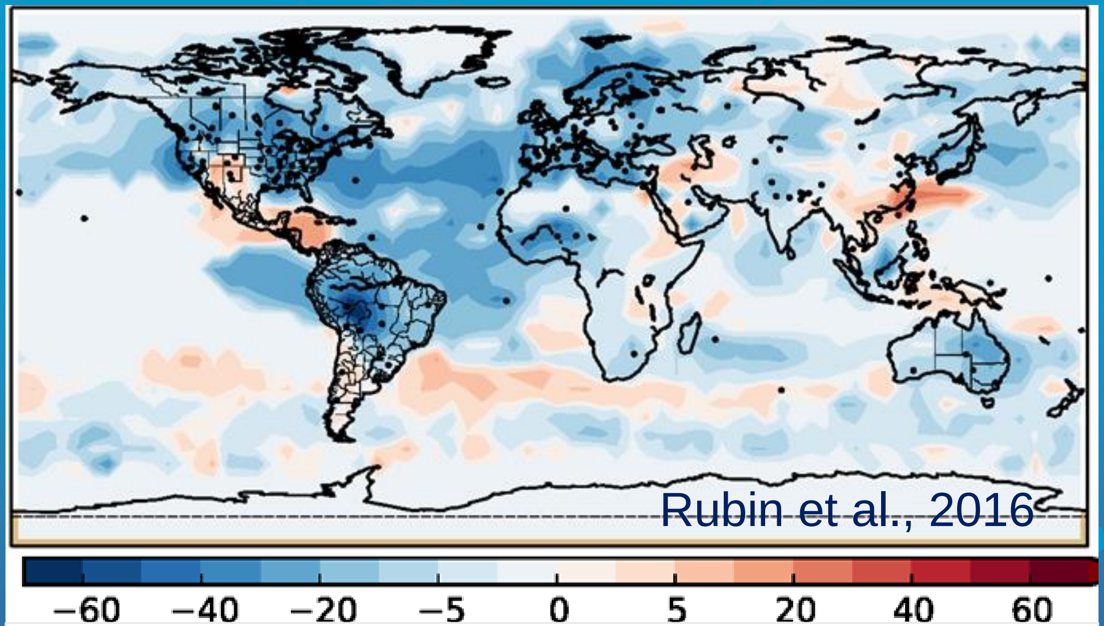
8 months after MODIS 'first light', we had validation!



Remer et al. (2002)

Operational Applications of AERONET

- **Global operational centers and aerosol model developers now ingest AERONET data in Near Real Time**
- **Model users include BSC, EU-Copernicus, ECMWF, FNMOC, GMAO, JMA, NCEP, NRL, UKMO**
- **Applications:**
  - **NRT Verification**
  - **Data Assimilation**
  - **Reanalyses**



% reduction in NAAPS AOT RMSE against MODIS with AERONET ENKF assimilation

New Version 3: AERONET Algorithm Advances

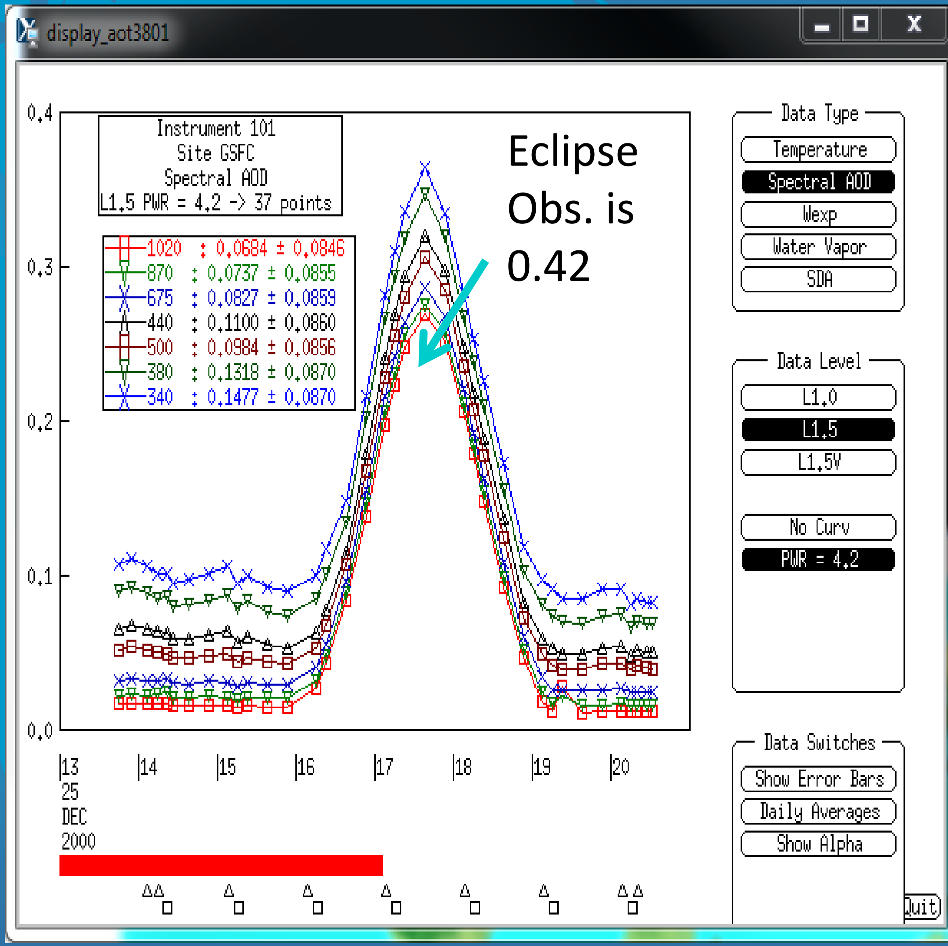
- AOD is less contaminated by optically thin cirrus clouds
- AOD is available for high aerosol loading biomass burning smoke events previously removed by Version 2
- Improved corrections including temperature
- AOD products are automatically controlled in NRT using new algorithms derived from manual QA methods (Level 1.5)

AERONET Version 3 L1.5: Solar Eclipse Screening

- Various solar eclipses affect AOD by changing incident extraterrestrial radiation

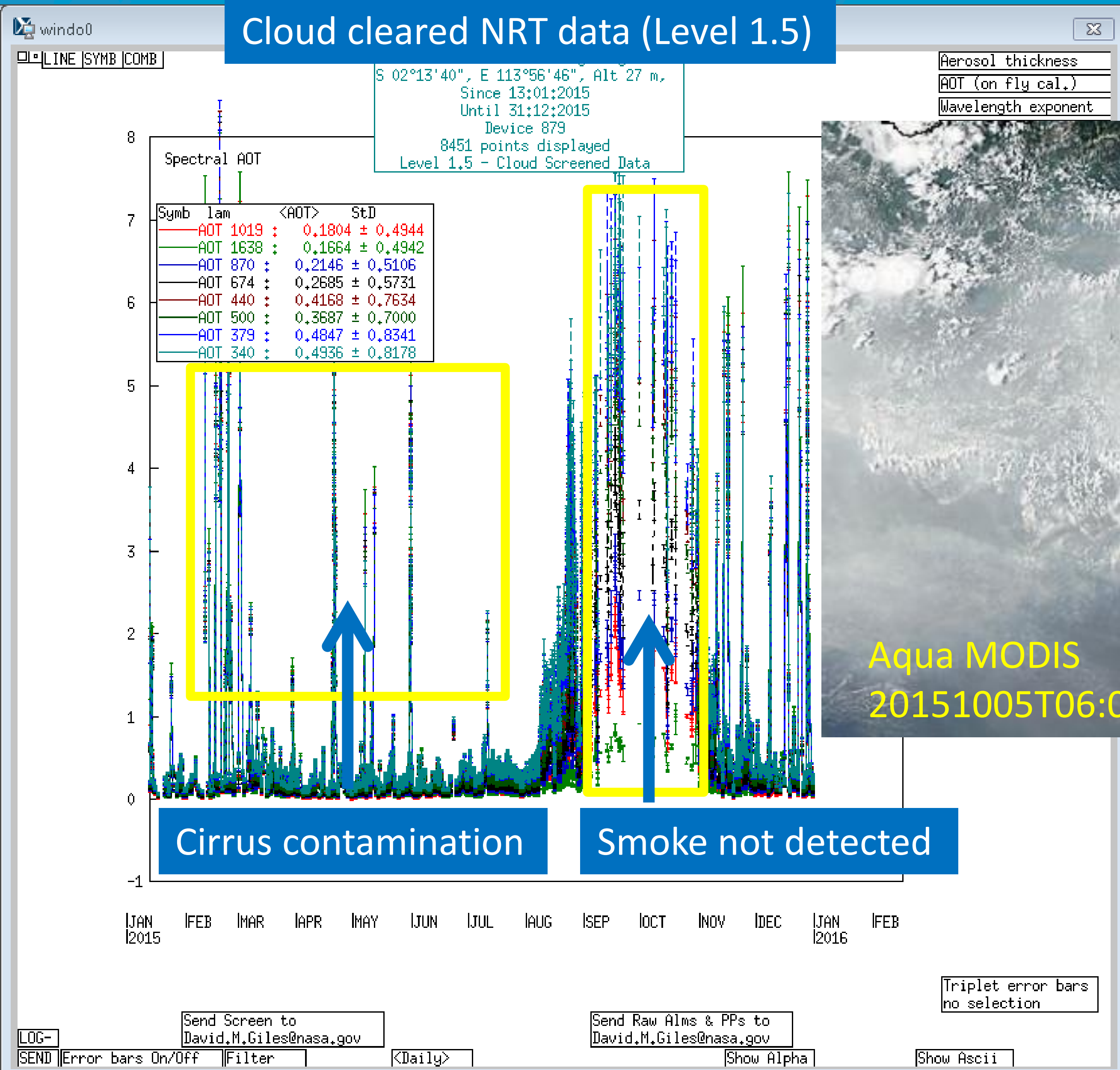
- AOD is maximum at maximum obscuration of the Sun
  - AOD calculation uses calibration coefficient that is not adjusted for eclipse

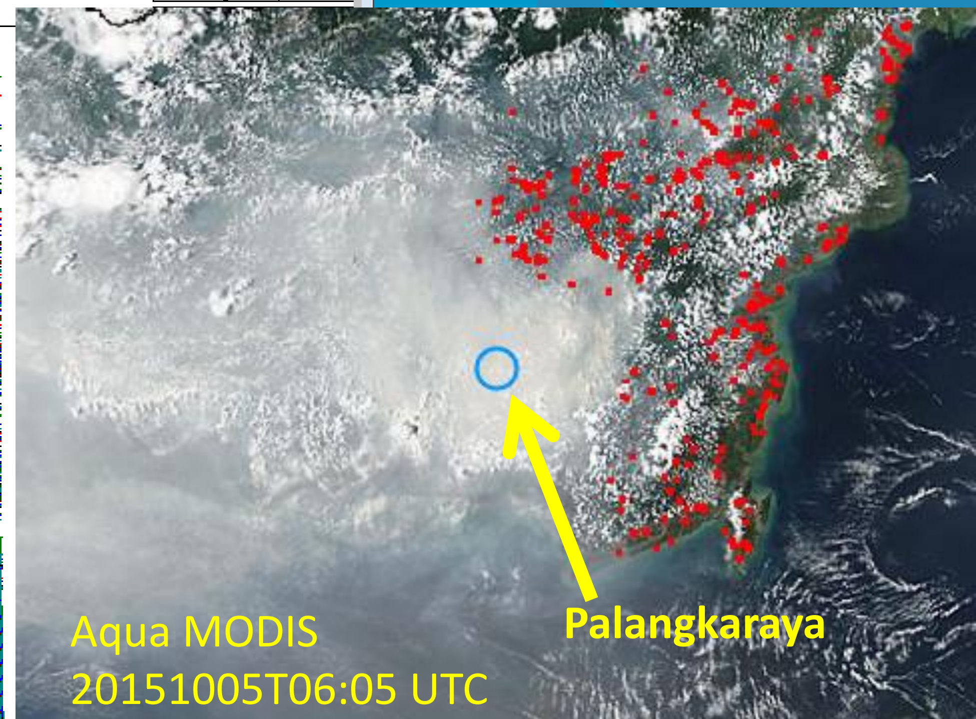
- NASA eclipse database utilized for screening: http://eclipse.gsfc.nasa.gov

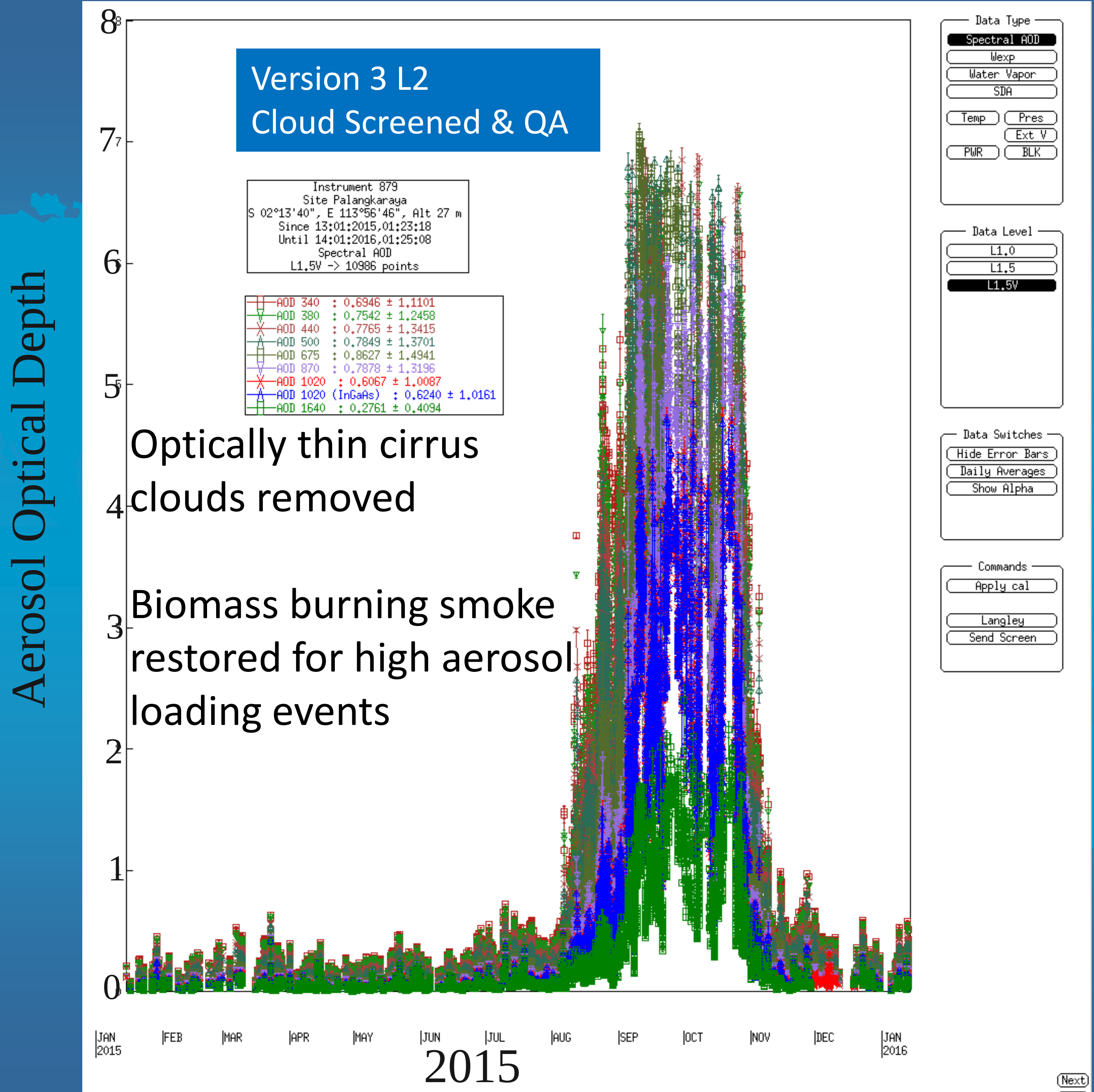


* AOD correction may be implemented

Indonesian Fires 2015 (Palangkaraya) – Current V2





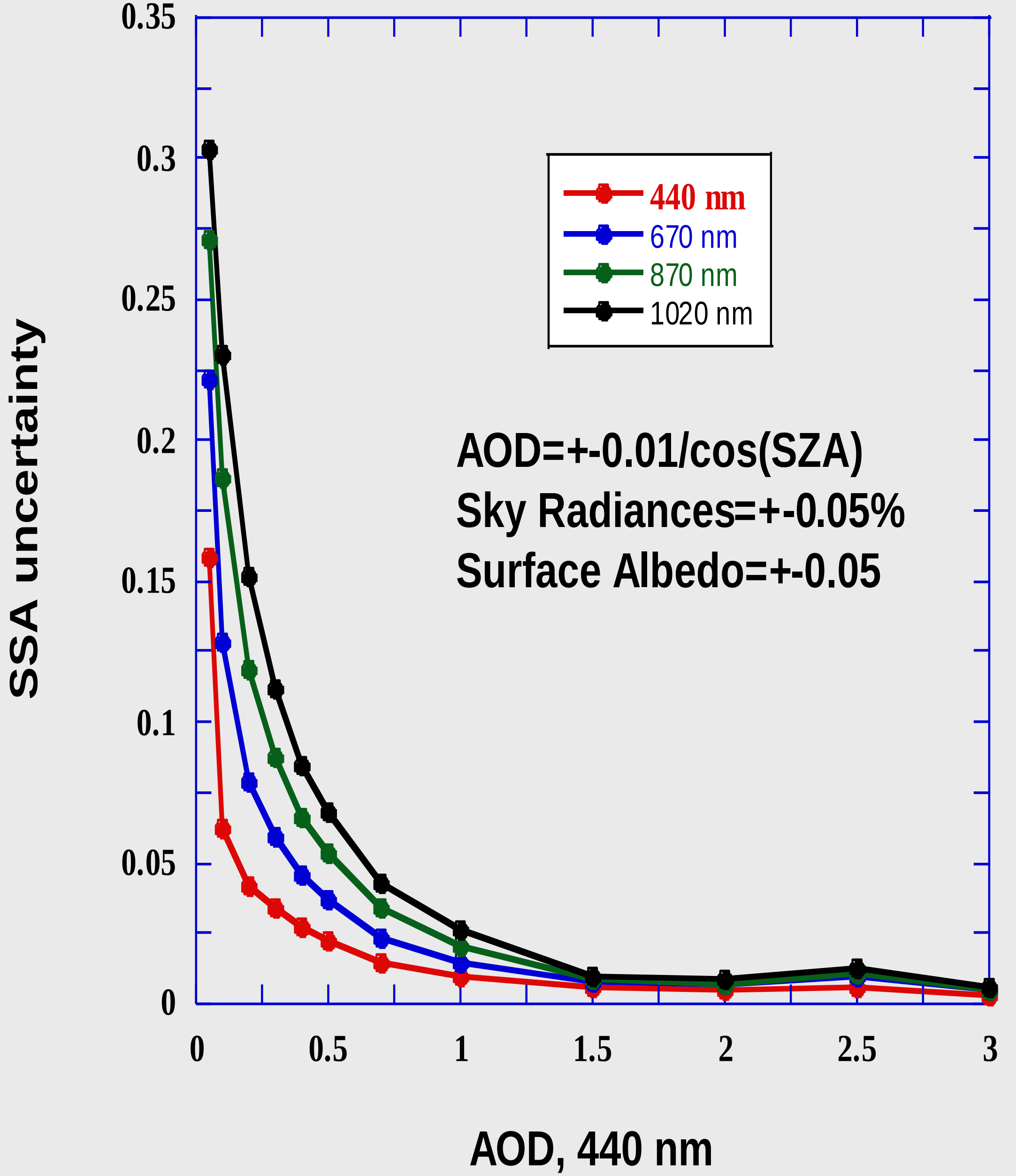


Version 3 L2
Cloud Screened & QA
Instrument 879
Site Palangkaraya
S 02°13'40", E 113°56'46", Alt 27 m
Since 13:01:2015,01:23:18
Until 14:01:2016,01:25:08
Spectral AOD
L1.5V -> 10986 points
AOD 340 : 0.6946 ± 1.1101
AOD 380 : 0.7542 ± 1.2458
AOD 440 : 0.7765 ± 1.3415
AOD 500 : 0.7849 ± 1.3701
AOD 675 : 0.8627 ± 1.4941
AOD 870 : 0.7878 ± 1.3196
AOD 1020 : 0.6067 ± 1.0087
AOD 1020 (InGaAs) : 0.6240 ± 1.0161
AOD 1640 : 0.2761 ± 0.4094
Optically thin cirrus clouds removed
Biomass burning smoke restored for high aerosol loading events
Aerosol Optical Depth
0
1
2
3
4
5
6
7
8
JAN 2015
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN 2016
2015
Data Type
Spectral AOD
Wexp
Water Vapor
SDA
Temp
Pres
Ext V
PWR
BLK
Data Level
L1.0
L1.5
L1.5V
Data Switches
Hide Error Bars
Daily Averages
Show Alpha
Commands
Apply cal
Langley
Send Screen
Next

V3-V2 AOD Statistics: Fractional gain/loss and changes of Multi-Year Averages

Aerosol Type	Site	N. Obs % change	N. Days % change	Δ AOD 500 nm	Δ AE (440870)
Fine Mode	GSFC	14%	12%	0.01	0.05
Fine M.	Singapore	29%	19%	0.04	0.14
Fine Mode	Mexico C.	1%	14%	0.06	0.09
Biomass B	Mongu	14%	4%	0.00	0.05
Dust	Banizom	-3%	-6%	-0.03	-0.01
Dust	Capo V	-6%	-21%	0.00	-0.04
Dust	Solar V.	7%	-1%	0.00	0.03
Dust + FM	Kanpur	19%	4%	0.00	0.03
Mixed	Beijing	2%	4%	0.11	0.03
Dust + BB	Iloren	-6%	-9%	-0.03	0.05
Marine	Midway	1%	-3%	0.00	0.00

GSFC aerosol type, SZA=60 degree



Version 3 releases

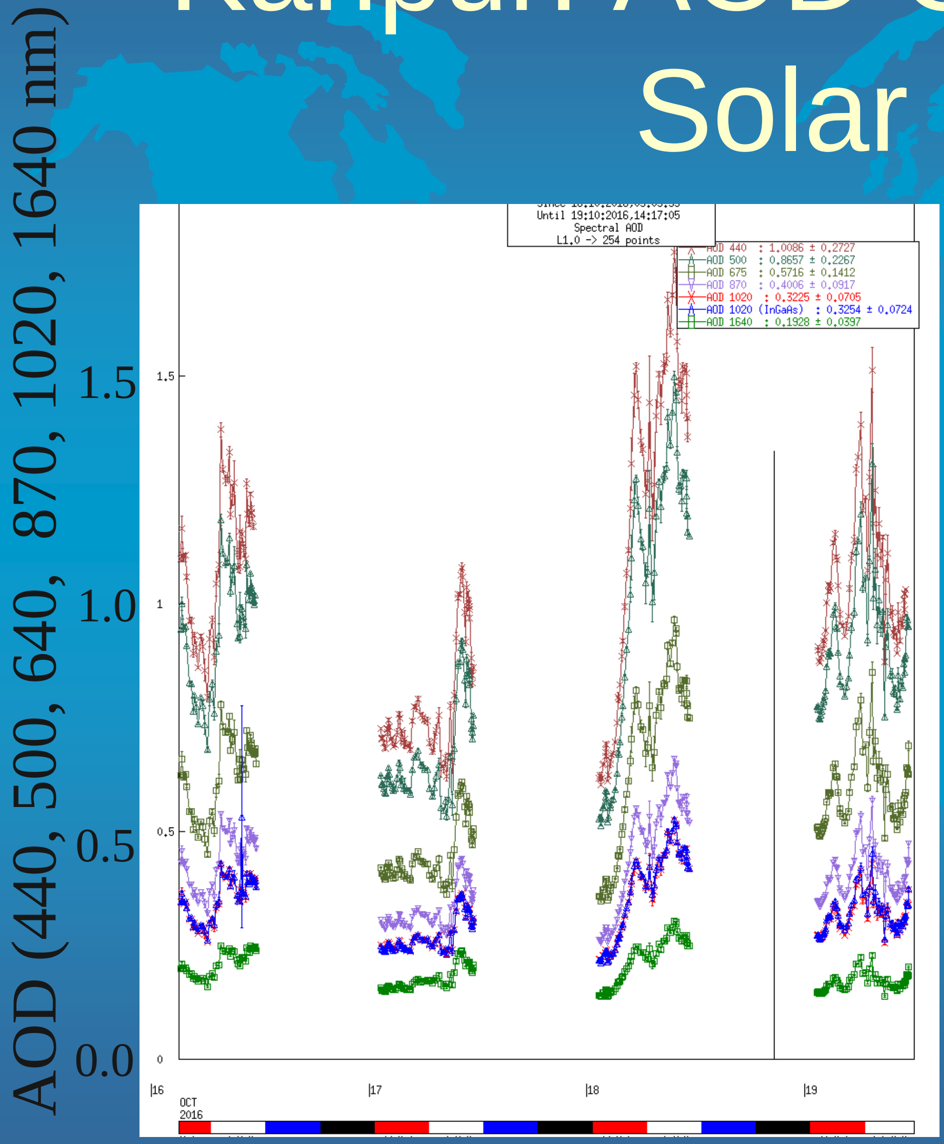
- AOD NRT (L1.5) August 2016
- AOD QA (L2.0) May 2017
- Inversions QA (L2.0) August 2017
- AOD Lunar Beta (L 1.0) Dec, 2016
- AOD Lunar QA (L2.0) TBD
- Hybrid Inversion NRT (L1.5) Aug 2017
- Hybrid Inversion QA (L2.0) TBD
- http://aeronet.gsfc.nasa.gov

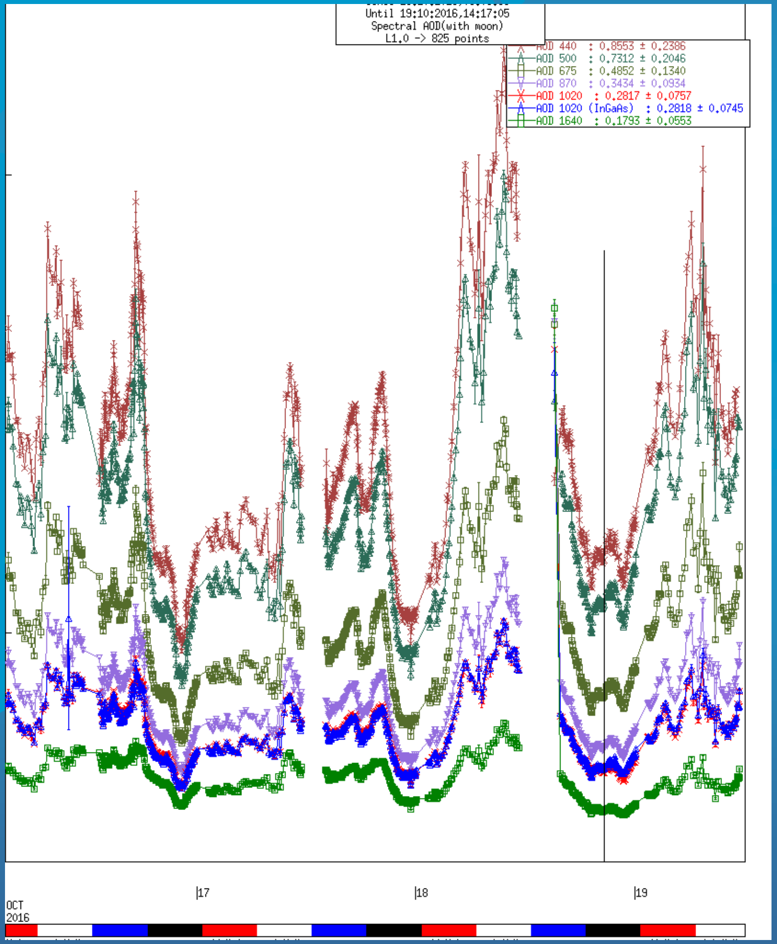
AERONET moving forward
New Instrumentation/Enhancements

- Greater control over instrument measurement scenarios (e.g., **Hybrid**)
- Lunar measurements
  - 1^{st} to 3^{rd} quarter lunar phase (waxing to waning gibbous)
  - Processing for lunar measurements (e.g., ROLO, Tom Stone)
- Synergism with MPLNET, PANDORA, and in situ (SPARTAN) measurements
- Development toward attachment for CO_2 measurements (LHR)
- Version 4: Better ancillary inputs

Cimel Sun/Sky/Lunar Radiometer

Kanpur: AOD Oct.16-19, 2016
Solar + Lunar



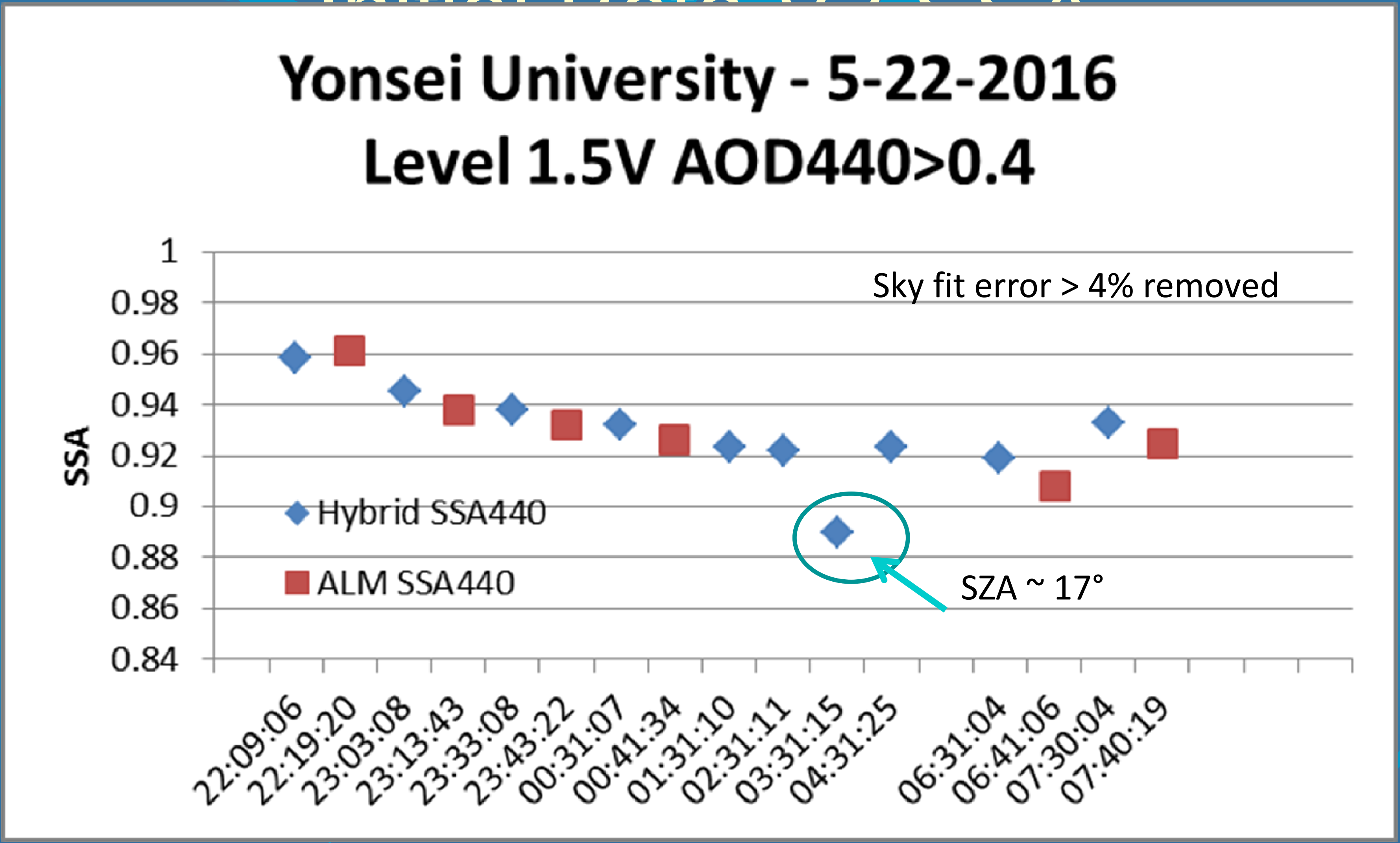


Make AERONET Great Again

- 1 Network
- 8 Sub-networks
- 5 Calibration facilities
- 33 Staff (GSFC, Photons, Rima, Izana, NEON)
- 97 Countries and territories
- 368 Local PIs
- > 500 sites
- 655 Local site managers
- 6 million sky scans
- 86 million AOD observations
- ~ 4350 citations of Holben et al., 1998

Thanks to Everyone!

Initial Beta V3 SSA



- Provide greater temporal coverage of inversion aerosol properties
- Hybrid important especially for polar orbiting satellite overpass

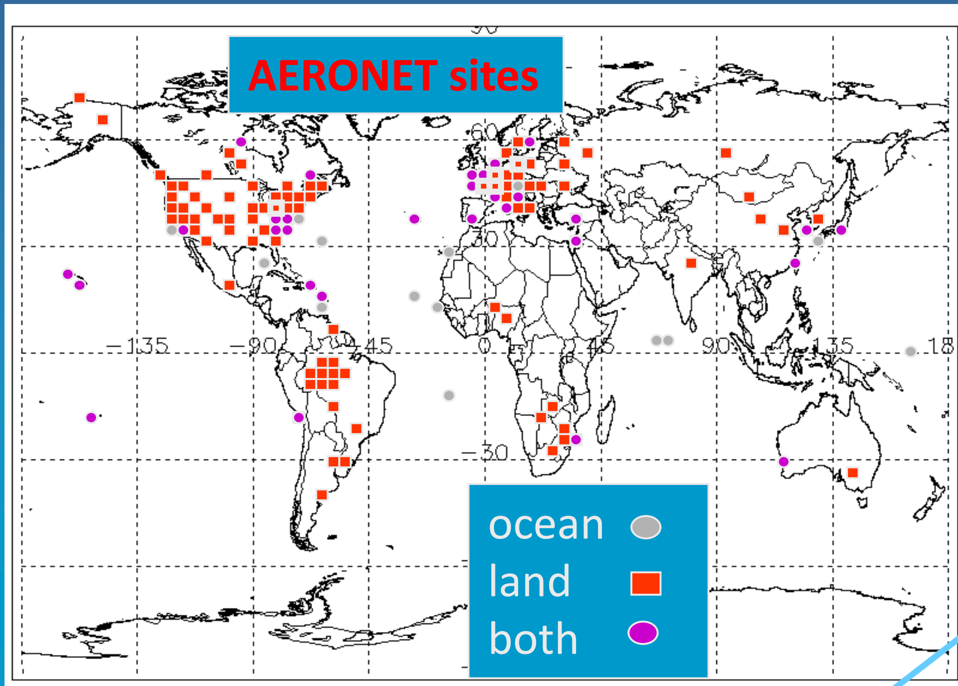
Uncertainties and biases

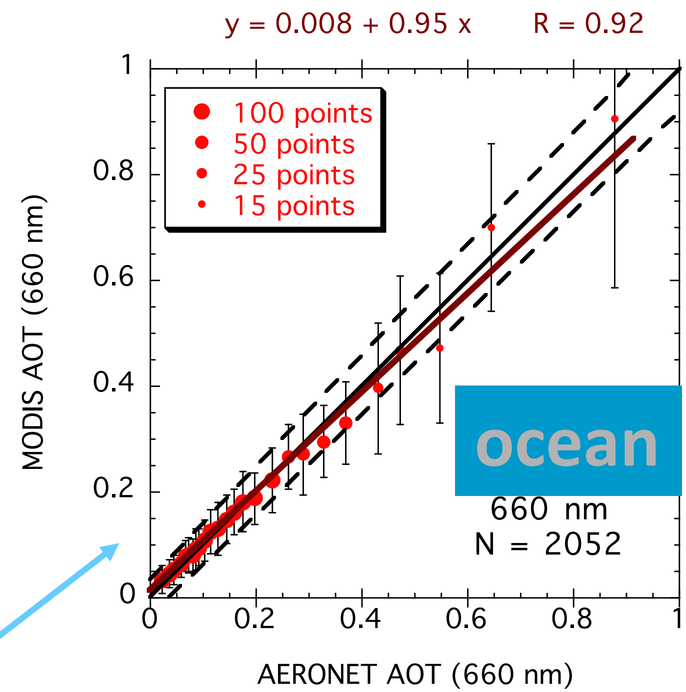
AOD: ±0.01/cos(SZA)
Sky Radiances: ± 5%
Surface albedo : ±0.05 (first parameter of BRDF model)

Geometry and AOD used:
SZA: 30, 50, 60, 70, 75
AOD: 0.05, 0.1, 0.3, 0.5, 0.7, 1.0, 1.5, 2.0, 2.5, 3.0

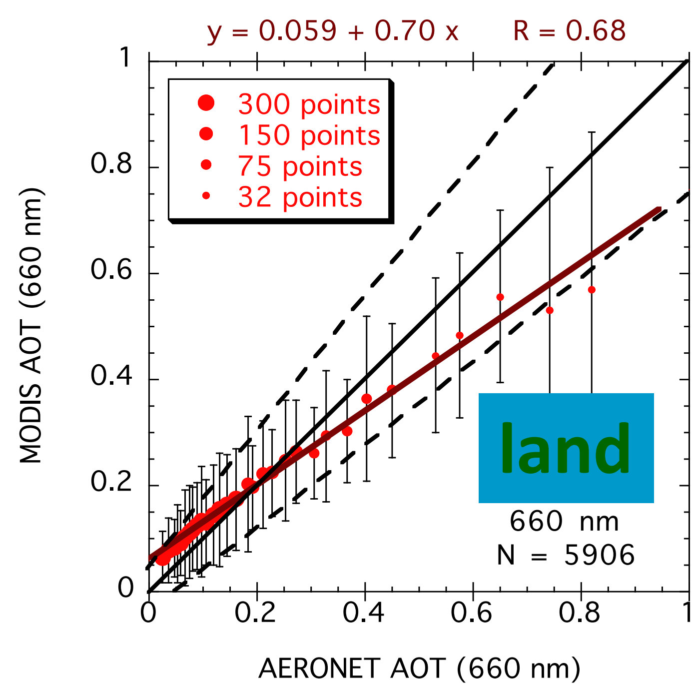
For each pair of AOD and SZA 8 combinations of uncertainties were used: ppp, pm
ppm, pmp, mpp, mmm, mmp, mpm. Where p means plus and m means minus. Firs
corresponds to AOD, second to sky radiance, and third to surface albedo. After nur
results were averaged over all the 8 combinations.

MODIS aerosol validation 2000-2002





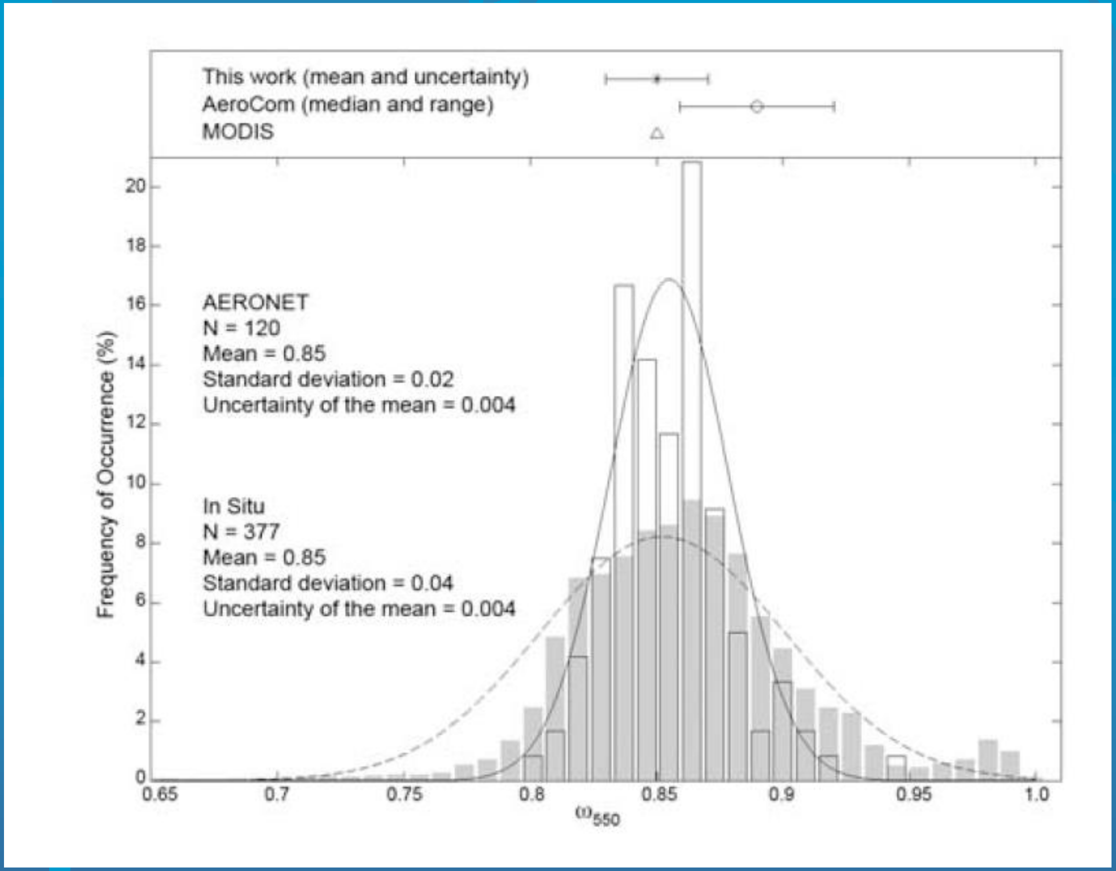
66% of MODIS aerosol retrievals over ocean fall within expected uncertainty



71% of MODIS aerosol retrievals over land fall within expected uncertainty

Remer et al. (2005)

SAFARI2000 Airborne *In Situ* Comparison to AERONET Single Scattering Albedo



Leahy et al., 2008

Level 1.5 Quality Control Algorithm

- Constant Digital Count Removal: Remove constant voltage digital counts
- Temperature Screening: Remove anomalous temperatures and channels significantly affected by temperature dependence
- Solar Eclipse Screening: Determine the existence of solar eclipse events and remove data affected by them
- Temporal Shift Screening: Evaluate data for overlap of UV channels only during one period during the day in the early AM or late PM
- AOD 1020nm Difference Check: If an extended instrument with InGaAs detector, check for good AOD 1020nm