Seasonal Variability in the SE U.S Background Aerosol Direct Radiative Effect –An Initial Measurement-based Climatology from a Regionally-Representative Location

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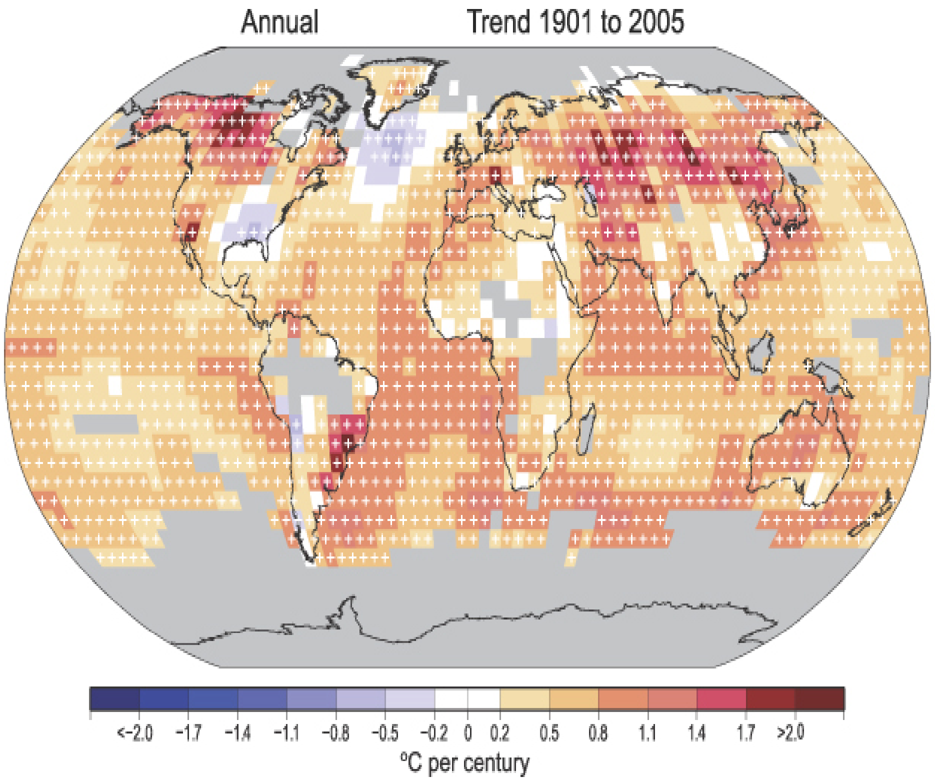
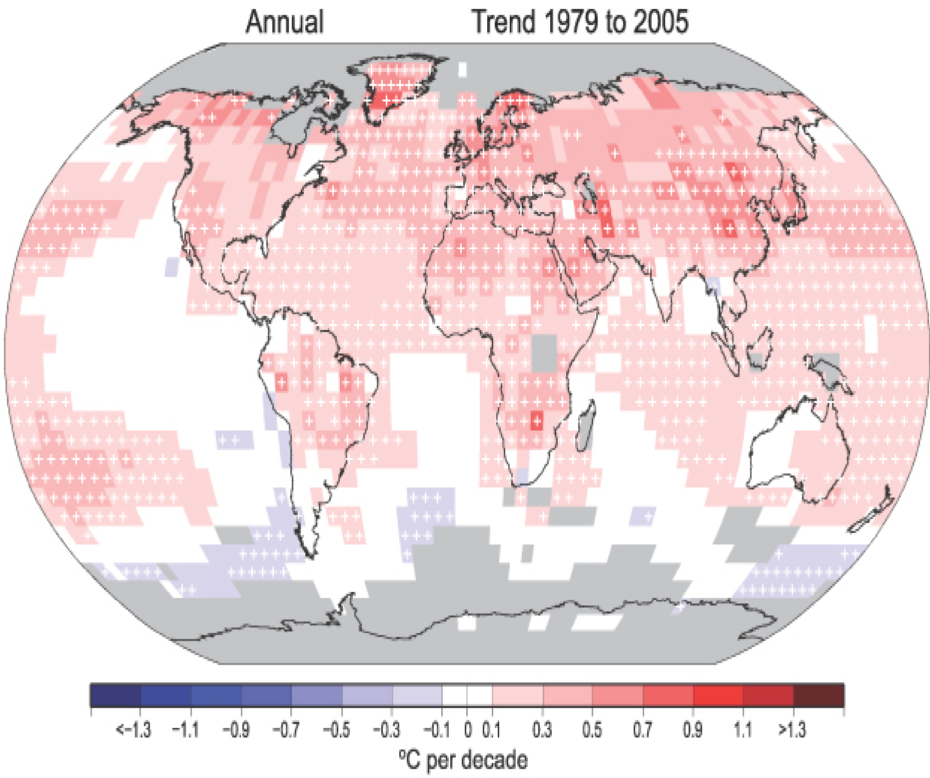
Outline

I. Relevance of long-term aerosol monitoring in SE U.S.
II. Regionally-representative aerosol monitoring at AppalAIR
III. Seasonal variability in aerosol loading, optical properties, and DRF
IV. Conclusions and Future Work

I. Relevance of long-term aerosol monitoring in SE U.S.





Trenberth, et al., 2007

- Southeastern U.S. is one of a few regions in world not to have warmed in 20th century, but is beginning to warm in recent decades

Relevance of long-term aerosol monitoring in SE U.S.

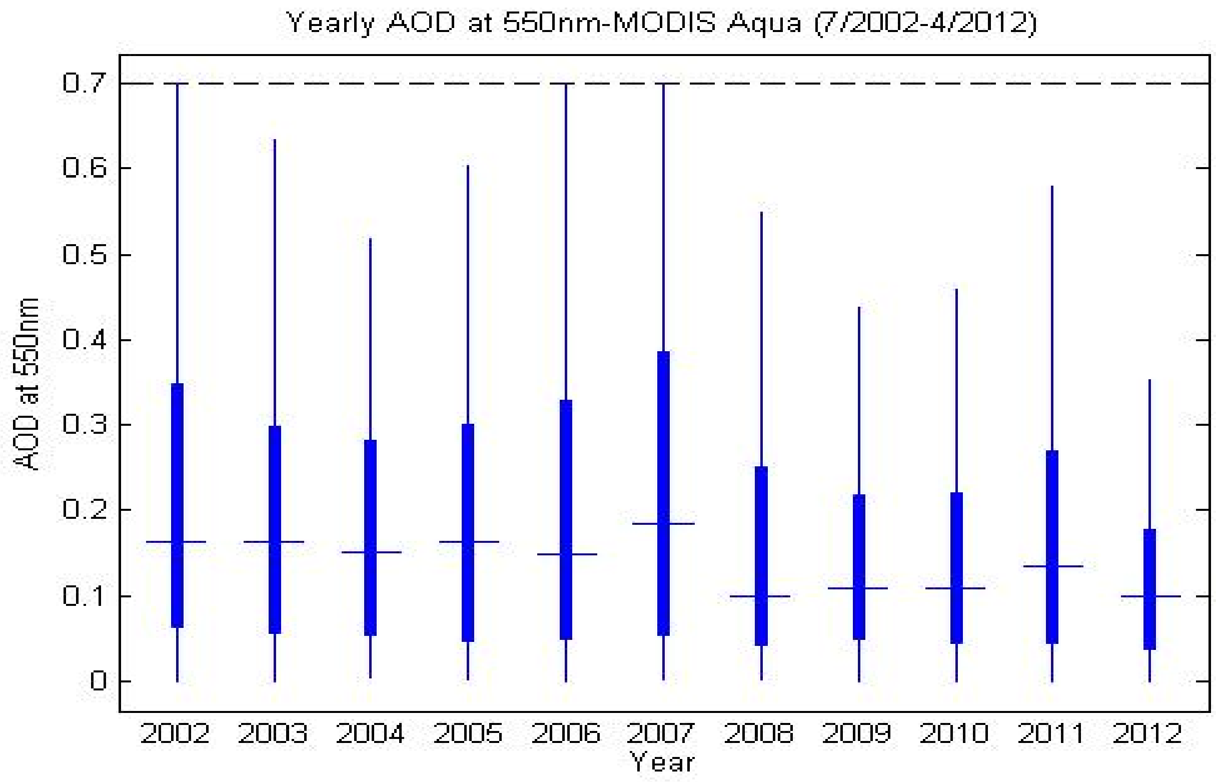
- Spatial pattern of AOD seasonality in SE U.S. matches BVOC emissions from regional forest (Goldstein, 2008) and is consistent with warm-season cooling effect at TOA

- Goldstein's study (based on MODIS/MISR/AERONET AOD, precursor gases suggests large influence of SOAs aloft), which is consistent with that of Hobbs, TARFOX, and other published results based on plane-based measurements over eastern U.S.

- Alston (2011) speculated that decrease in PM 2.5 in Georgia between 2000-2009, accompanied by mild decrease in regional AOD, may be enhancing a recent trend in solar brightening that has been observed by Dutton over the past 15 years

- Despite these and other efforts, there have been no long-term ground-based monitoring of AOPS, loading, and vertical distributions from <u>regionally-representative</u> SE U.S. locations to validate satellite-based DRF estimates and better constrain models

What are long-term relationships between regional air quality and climate change?



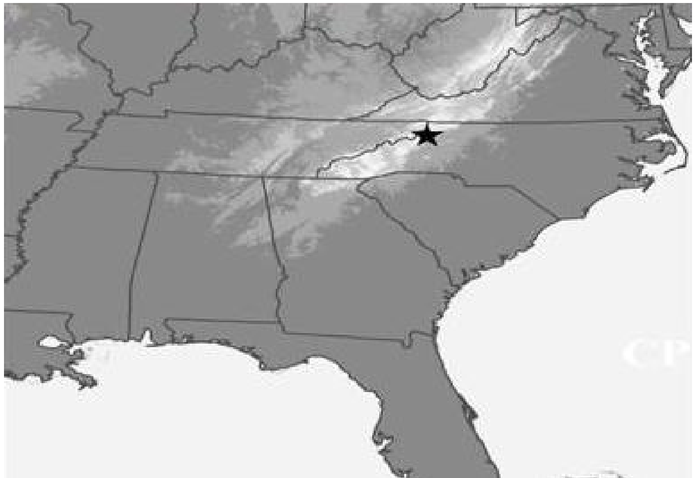
Somewhat lower mean AOD in recent years, coupled with decrease in SO_2 and NO_2 levels. What will the feedback mechanisms be in terms of regional surface temperatures?

II. Regionally-representative aerosol monitoring at AppalAIR

- Appalachian Atmospheric Interdisciplinary Research: air quality/climate research and public outreach facility for exploring air pollution formation and transport and the relationship of pollution to a changing climate and its effects on regional ecosystems

- Boone, NC 1076 m, lat 36.2° lon -81.7° (small-town mountain location)

- Only co-located NOAA-ESRL collaborative aerosol monitoring site and NASA AERONET site east of Mississippi River



NASA

Appalachian STATE UNIVERSITY

NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

Aerosol Instruments and Collaborators

Table 1: Data Product	Measurement Technique
• Aerosol light absorption at 467nm, 530nm, 660nm wavelengths (size-resolved, sub-um, sub-10um) • Aerosol total light scattering and hemispheric backscattering at 450nm, 550nm, and 700nm (size-resolved, sub-um, sub-10um) • Aerosol Number Concentrations • Aerosol chemical composition (size-resolved, sub-um)	Radiance Research Particle Soot Absorption Photometer (PSAP) TSI 3563 Nephelometer TSI 3010 Condensation Particle Counter (CPC) Aerodyne Aerosol Mass Spectrometer
• Aerosol hygroscopic growth: total light scattering & hemispheric backscattering	TSI 3563 Nephelometer operating at a reference RH (≤40%) in series with a TSI 3563 scanning a higher RH range (up to 85%)
• Aerosol size distributions • Spectral Aerosol Optical Depth (AOD) at eight wavelengths between 340-1020nm	TSI Scanning Mobility Particle Sizer (SMPS) CIMEL 318 Solar-Tracking Sun/Sky Radiometer
• Vertical profiles of aerosols and clouds*	Sigma Space MPL-4 Micro-pulsed lidar
• C_2-C_{10} NMHCs, C_1-C_2 halocarbons, C_1-C_5 alkyl nitrates, OVOCs, reduced sulfur gases, HCN & CH_3CN	Cryogen free in-situ 5 channel GC/GC-MS system
• Selected VOCs and OVOCs; CO, CO_2, CH_4, N_2O & SF_6	Proton Transfer Reaction-Mass Spectrometer; 2 channel in situ GC

Instruments and Collaborators (continued)

Other Measurements

- Trace gases – O_3, CO_2, and H_2O
- Standard and Micrometeorology
- All-Sky Imager (Yankee Scientific TSI-440)
- Direct and Diffuse Irradiance (Kipp&Zonen CM22)
- Present Weather Detector (Vaisala PWD12)

Collaborators

- NOAA ESRL Global Monitoring Division
- NASA AERONET
- NCDENR Division of Air Quality
- NC State and UNC-Asheville

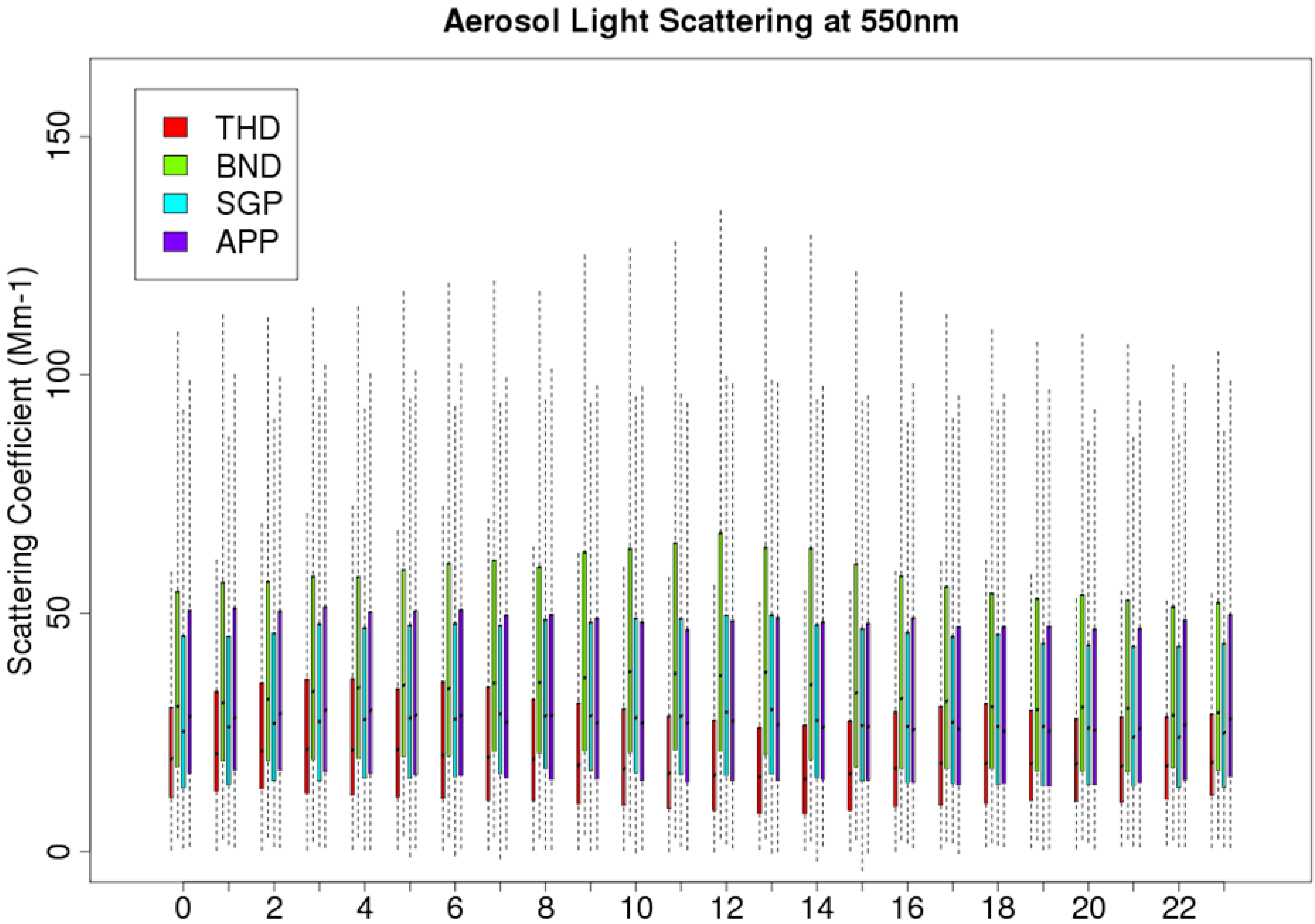
Data archived in near real-time to:

- NOAA ESRL and NASA AERONET websites
- Global Aerosol Watch (GAW) World Data Center for Aerosols (WDCA) web-based data archive.
- NCDENR Division of Air Quality website (expected online in fall 2011)

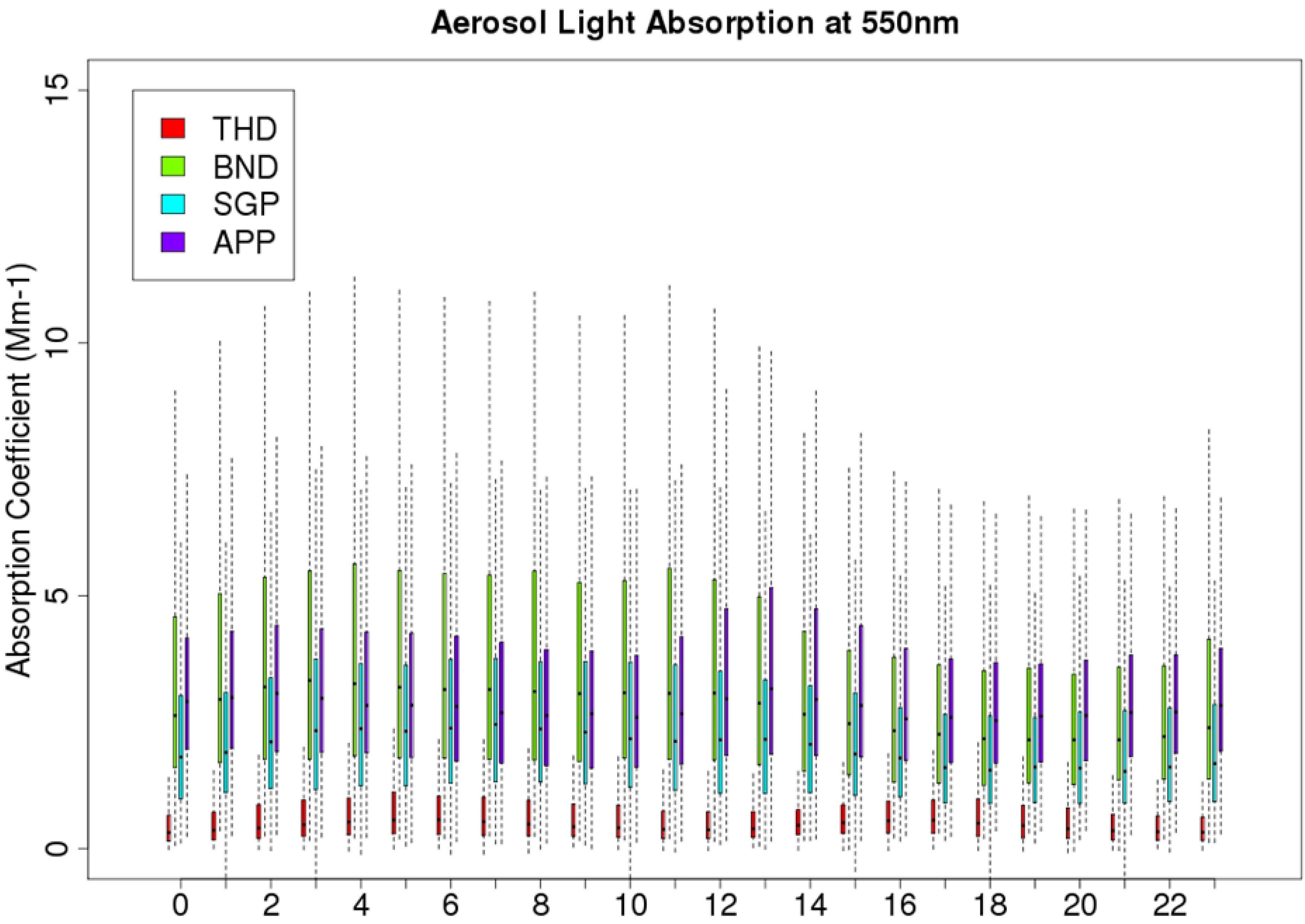
Are AppalAIR Aerosol Measurements Representative of SE U.S.?

- We make claim that our measured aerosol AOPs and AOD provide good approximation to SE U.S. background aerosol
- AOPs can then be scaled by location specific RH , AOD, and surface albedo to estimate DRF
- Necessary conditions for regional representativeness include
  (a) lack of significant local influence on measured AOPs
  (b) spatial homogeneity of aerosol properties (at least on timescales of weeks, for seasonal studies)

The following slides illustrate local influence comparable to other NOAA ESRL sites in U.S.

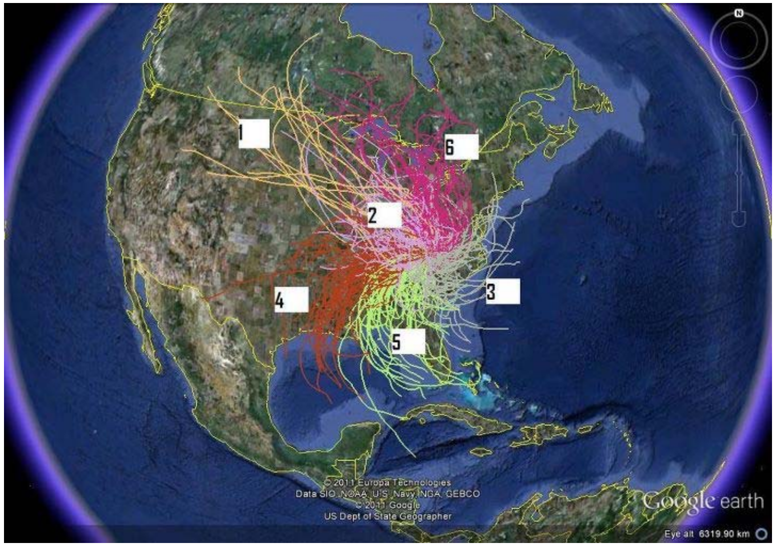


Aerosol Light Scattering at 550nm
THD
BND
SGP
APP
Scattering Coefficient (Mm-1)
0
50
100
150
0
2
4
6
8
10
12
14
16
18
20
22

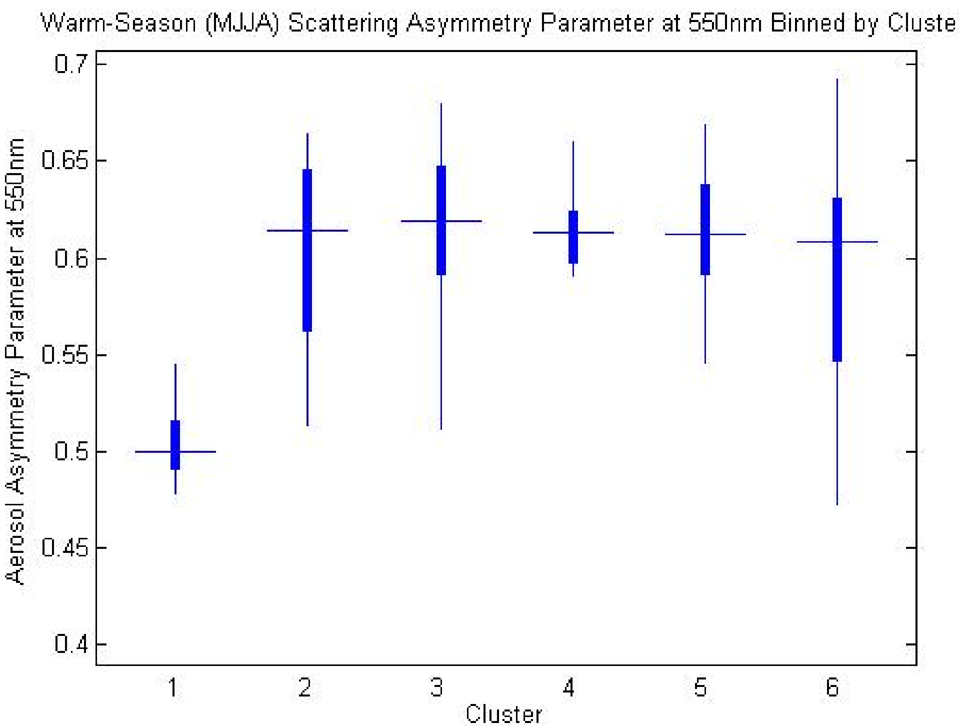


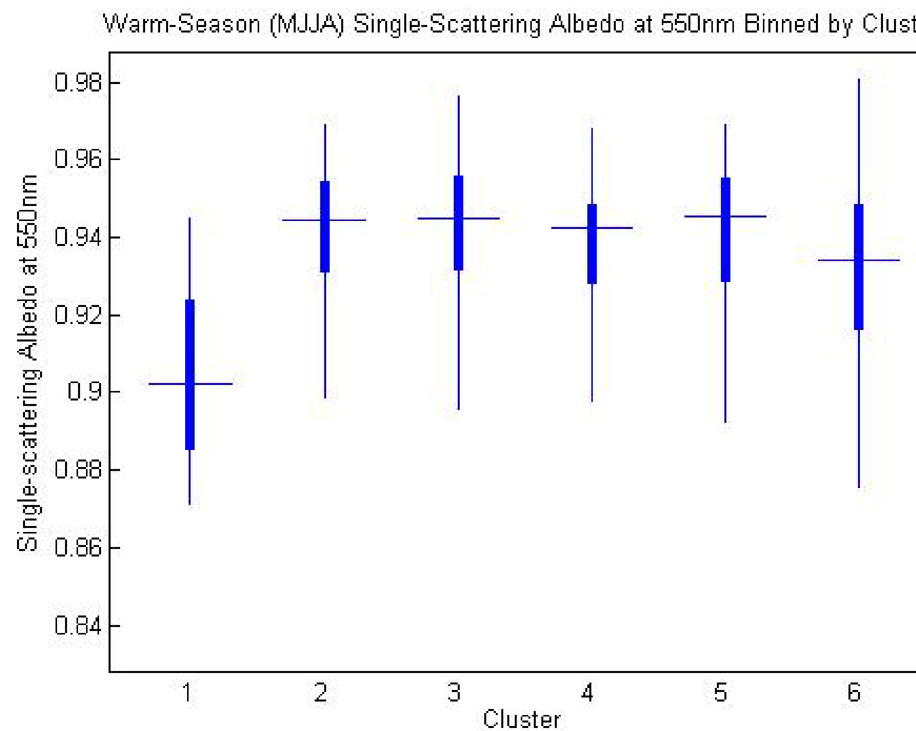
Aerosol Light Absorption at 550nm
Absorption Coefficient (Mm-1)
0
5
10
15
THD
BND
SGP
APP
0
2
4
6
8
10
12
14
16
18
20
22

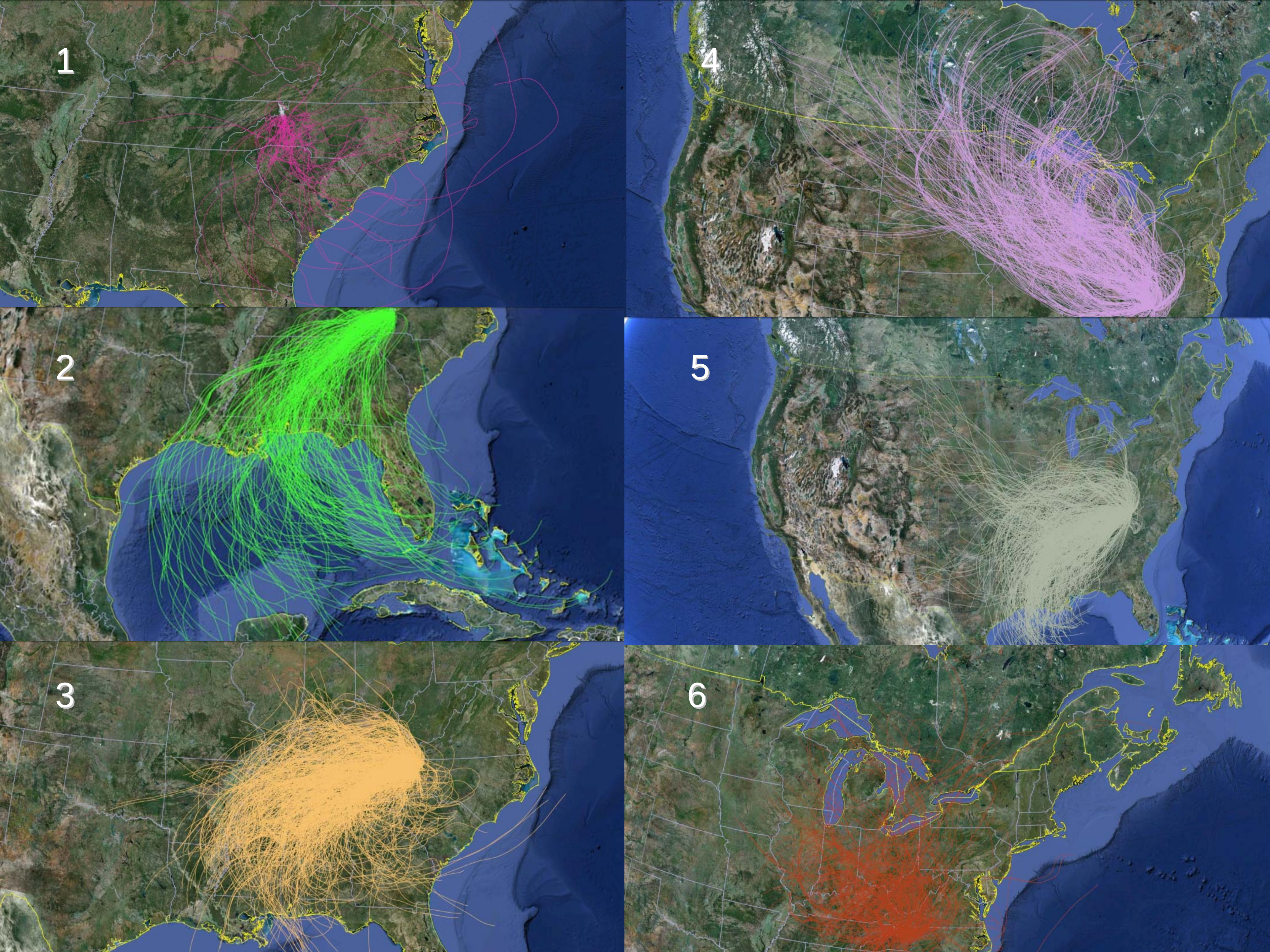
Are AppalAIR Aerosol Measurements Representative of SE U.S.?



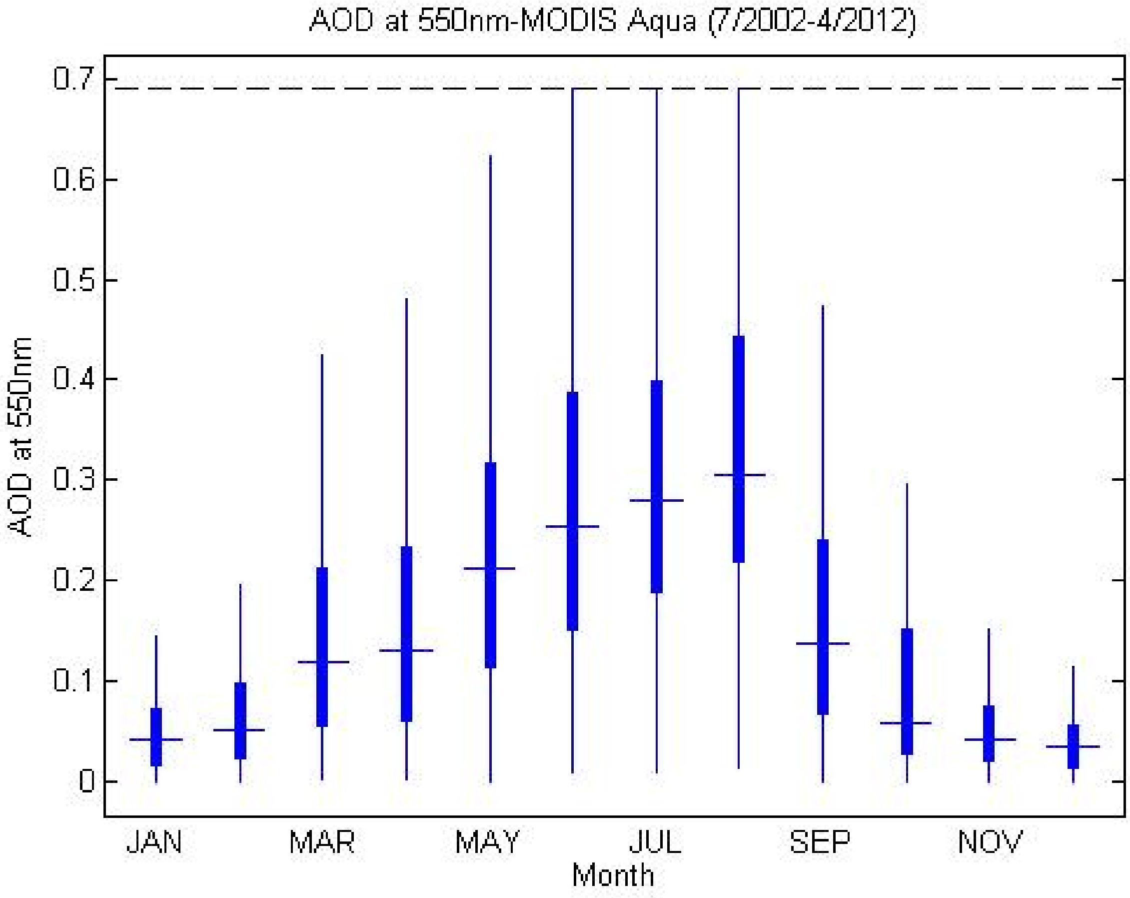
- 72-hour HYSPLIT back-trajectories for summer 2009-2010 hourly profiles were binned by air mass
- AOPs fairly constant with air mass (homogeneity of regional AOPs)
- Winter clusters were different than warm-season but also similar enough to call regionally-representative





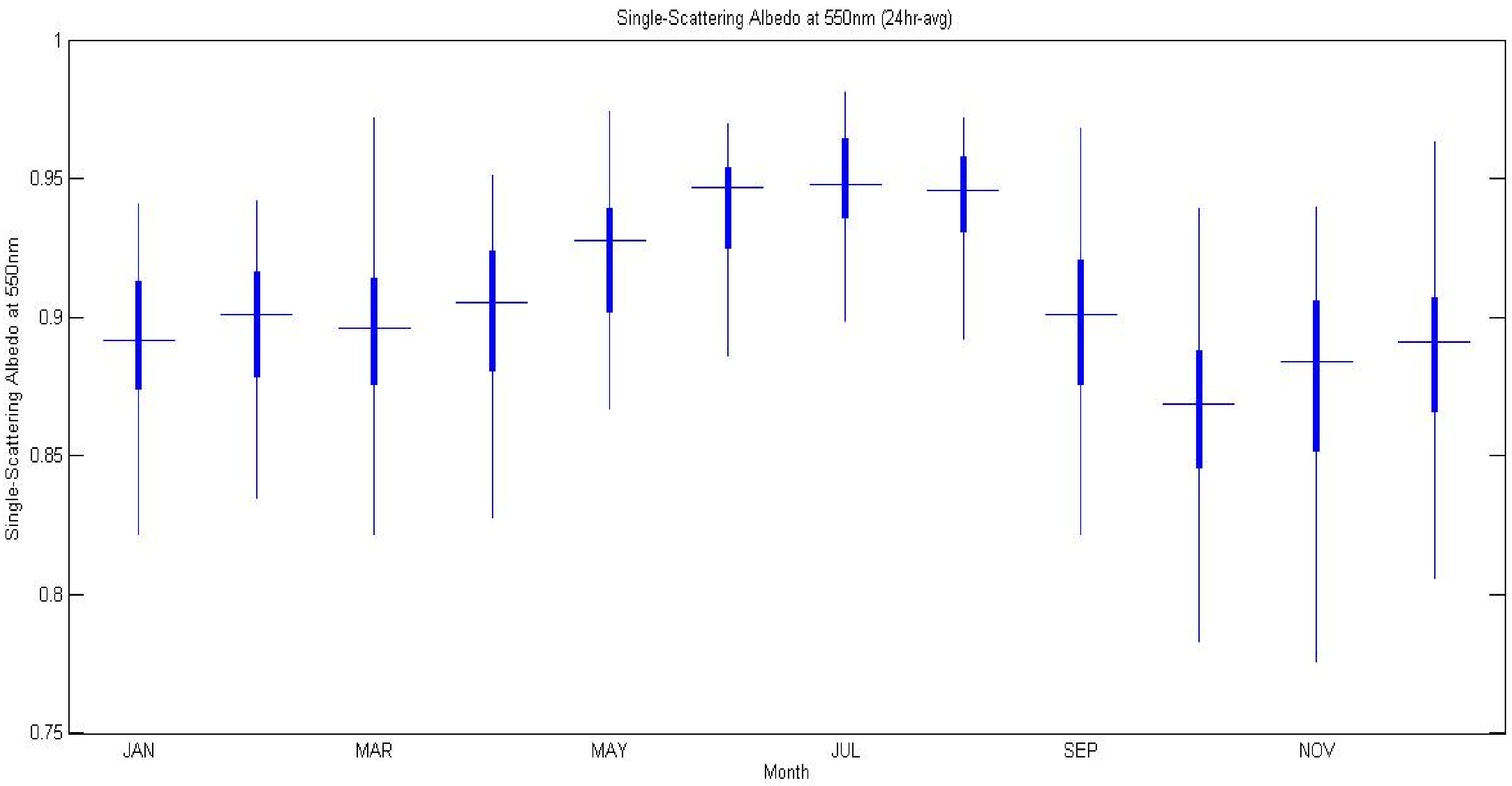

1
2
3
4
5
6

III. Seasonal variability in aerosol loading, optical properties, and DRF

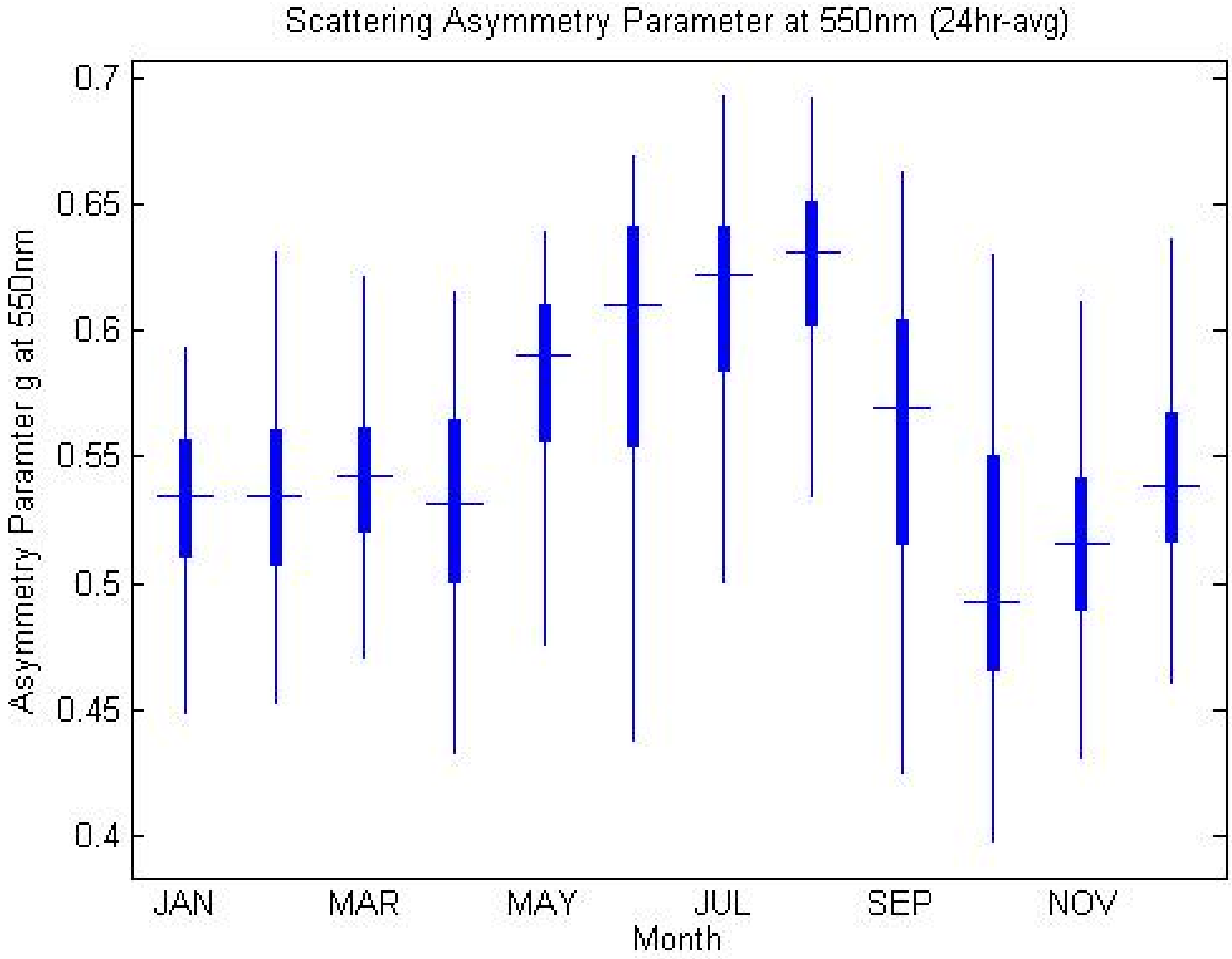


Factor of ~6-7 summer/winter AOD ratio similar to those of other SE U.S. regional studies (Goldstein, Alston) and larger than that reported for AERONET sites in eastern U.S. (factor of ~3.5) although there was substantial urban influence observed at several of these sites (Zhou, 2005)

Seasonal Variability in Lower Tropospheric Aerosol Optical Properties



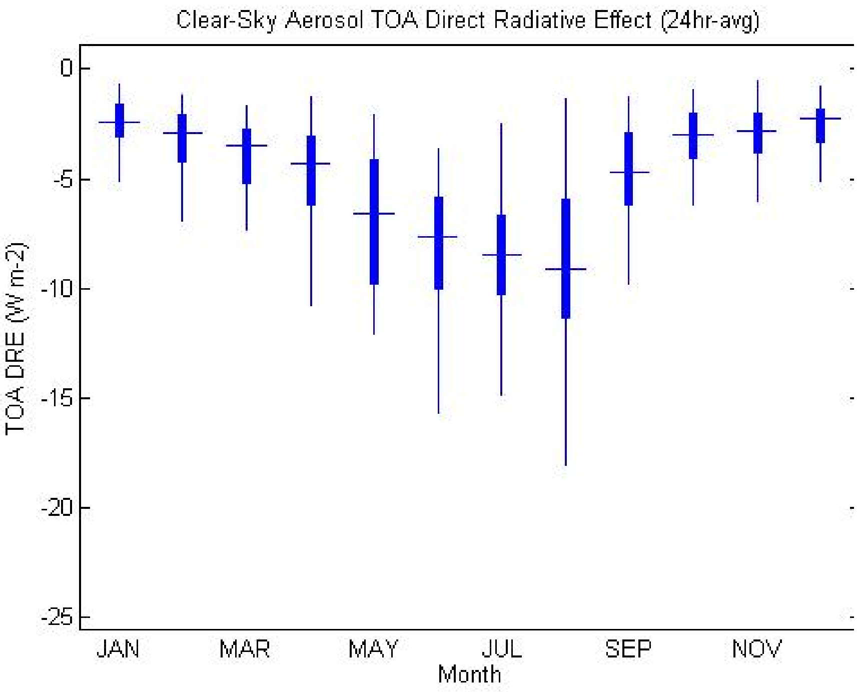
Seasonal Variability in Lower Tropospheric Aerosol Optical Properties

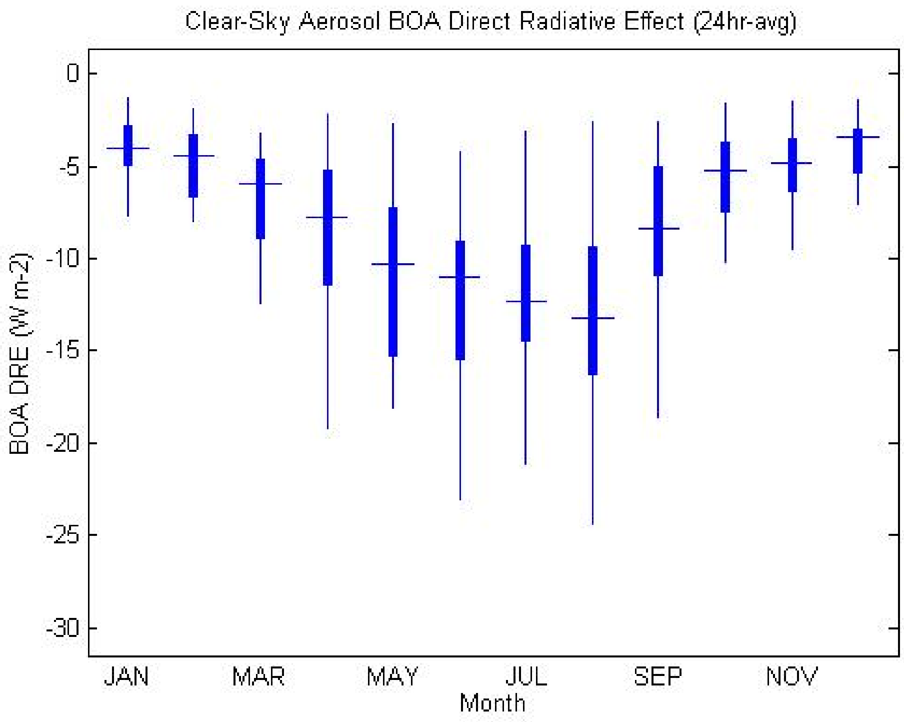


Seasonal Variability in Clear-Sky TOA and BOA DRF

- Hourly-averaged AOPs, and daily MODIS Terra and Aqua AOD and 8-day surface albedo serve as inputs to SBDART radiative transfer code (Ricchiazzi, 1998)
- Code run over full diurnal cycles to yield daily-averaged DRF, which is binned by month
- Clouds turned off
- No attempt to correct AOPs for RH-dependence in light scattering

Seasonal Variability in Clear-Sky TOA and BOA DRF (June 2009-October 2011)





- Aerosols primarily affect southeastern U.S. solar radiation budget during
- warm season , where they produce a net cooling effect at both TOA and at surface
- Difference between BOA and TOA DRF less than values reported in other studies
- Zhou(2005) quotes DJF/MAM/JJA/SON TOA values of -2.8/-8.0/-11.1/-4.5 and BOA values of -5.2/-12.8/-23.9/-10.8
- Yu(2001) quotes TOA/BOA values of -5.3 / 17 for summer/fall combined

IV. Conclusions and Future Work

- We believe that AOD and AOPs measured at AppalAIR provide a good estimate for the SE U.S. background aerosol
- Large seasonability in AOD (factor of ~6-7) seems to drive the seasonally-dependent DRF
- Difference between warm-season BOA and TOA DRF is less than that reported in other published works, although the different techniques make direct comparisons difficult

Future Work

- Aerosol chemistry and microphysical properties, used along with trace gas measurements and HYSPLIT back-trajectories to estimate anthropogenic fraction of DRF
- Use of vertically-resolved cloud and aerosol profiles and cloud optical properties (optical depth, cloud fraction, droplet radius) to estimate DRF under partly-cloudy conditions
- Evaluating satellite aerosol retrievals (lidar, CIMEL)

Acknowledgements

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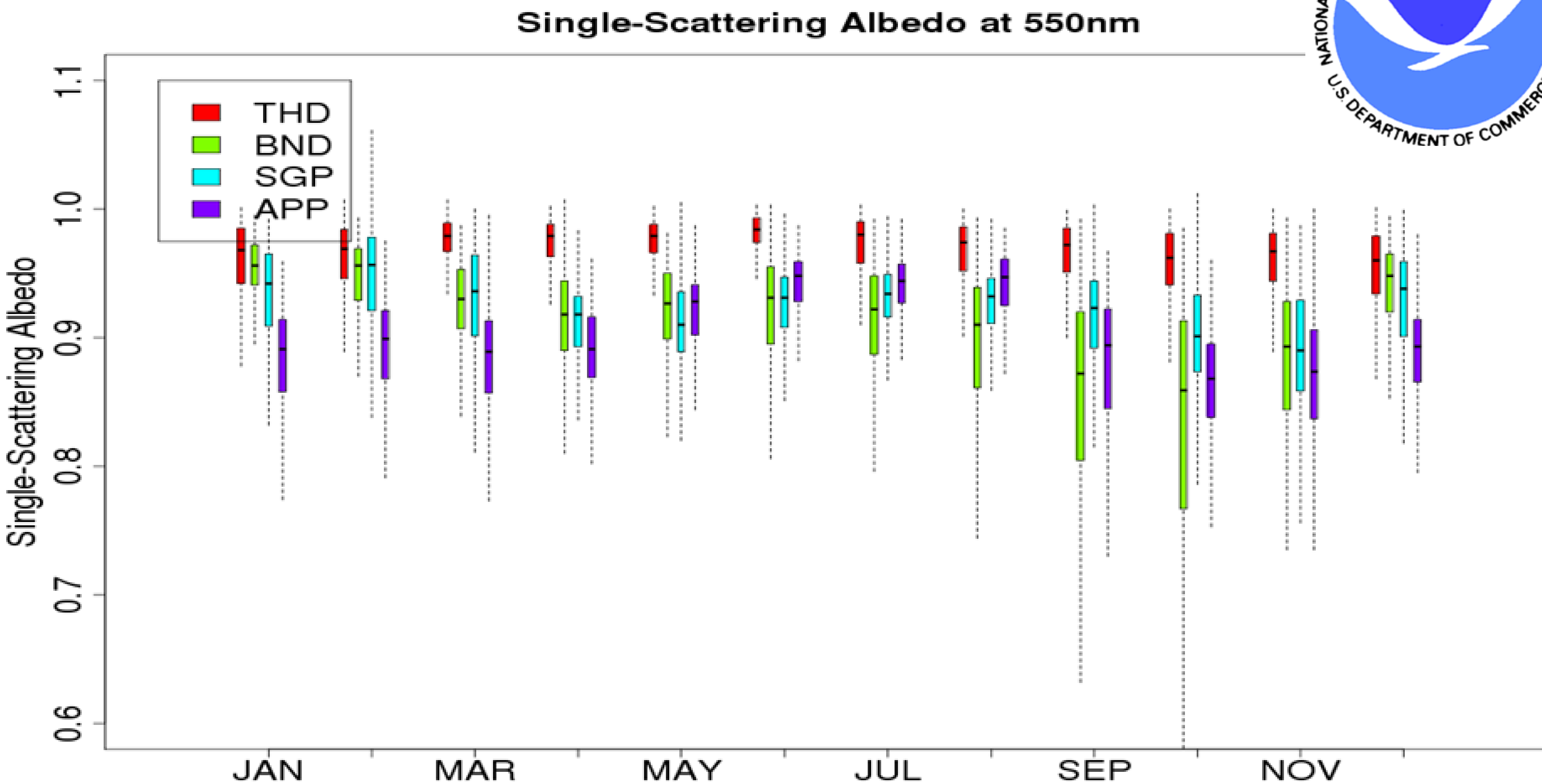
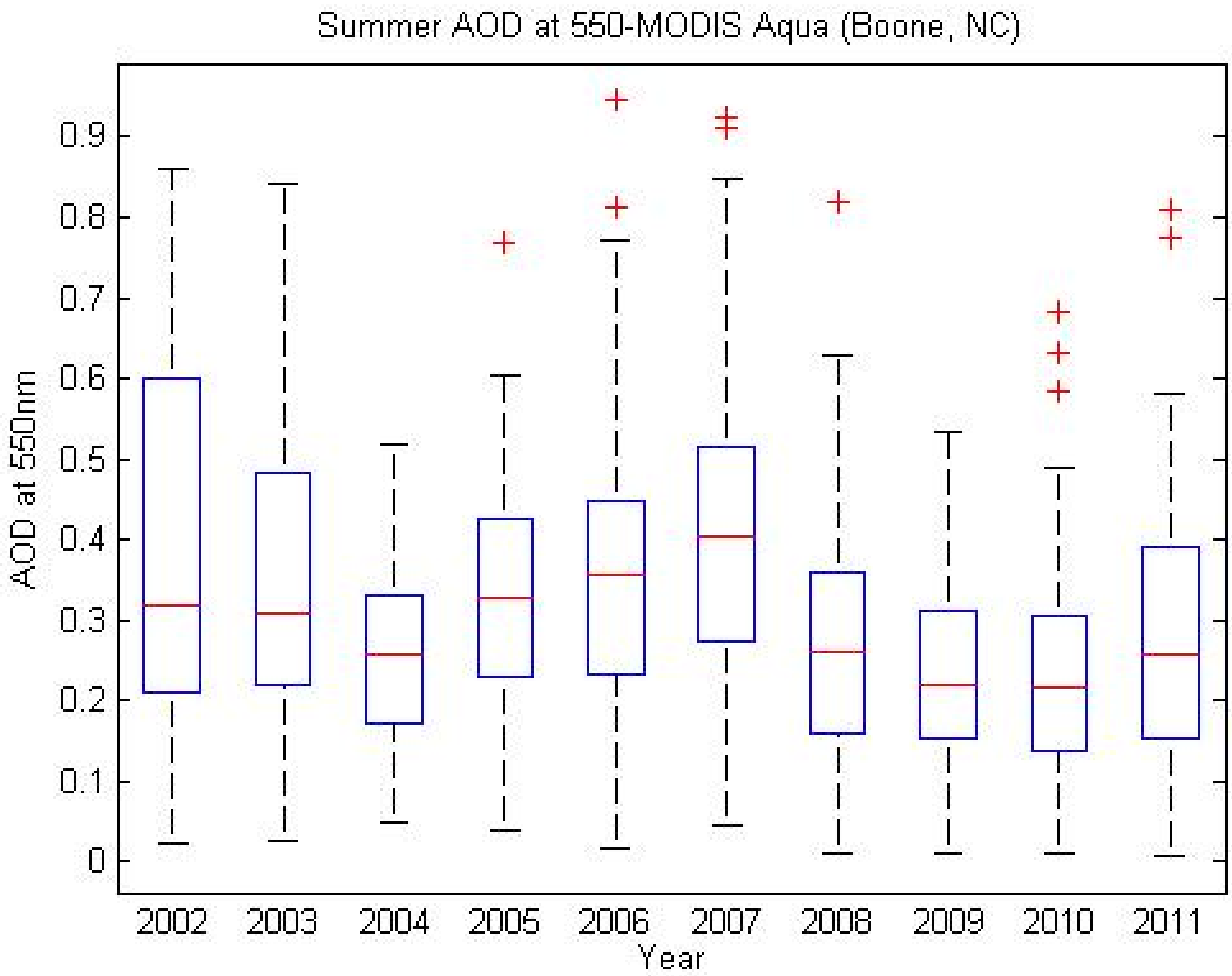
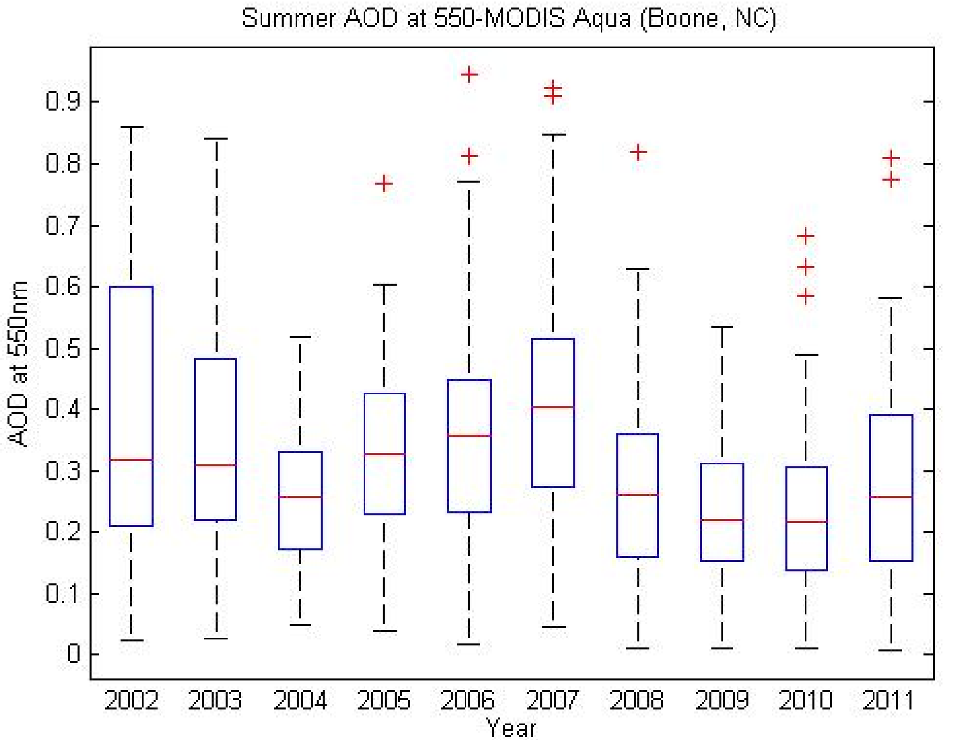
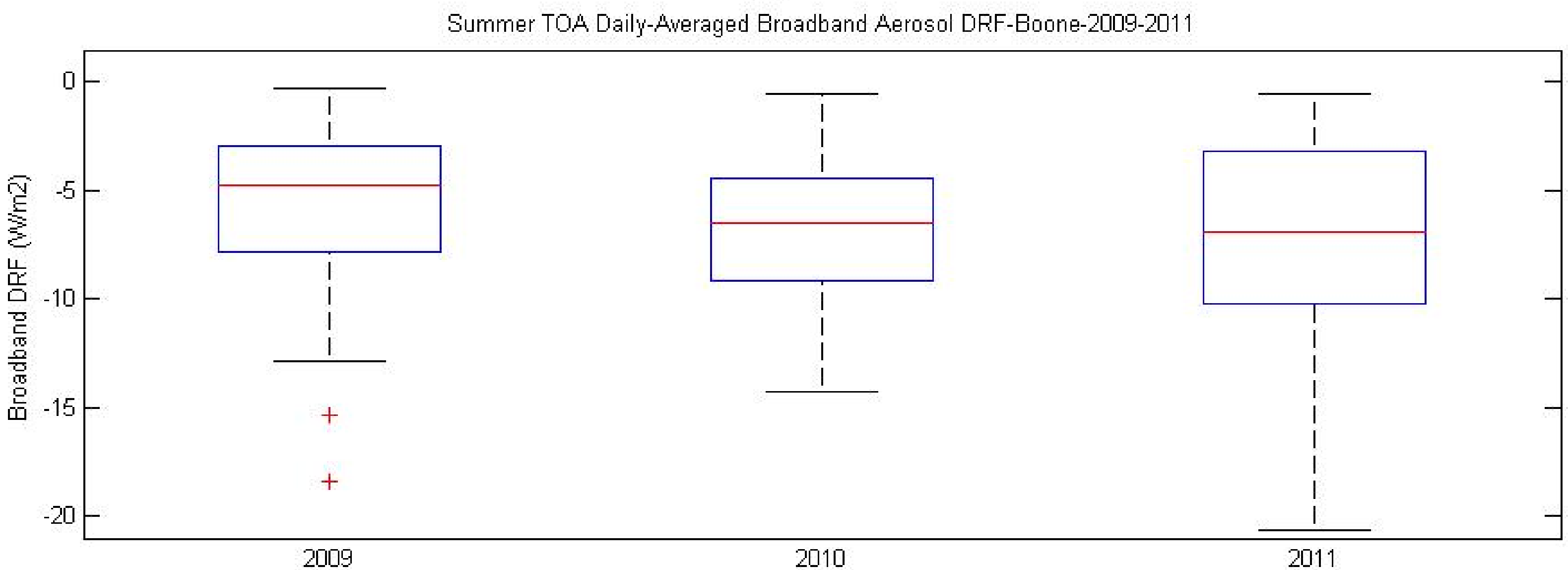


- Single-scattering albedo represents the fraction of light extinction (scattering plus absorption) due to scattering
- Larger SSA corresponds to greater cooling effect (for a given amount of light extinction)

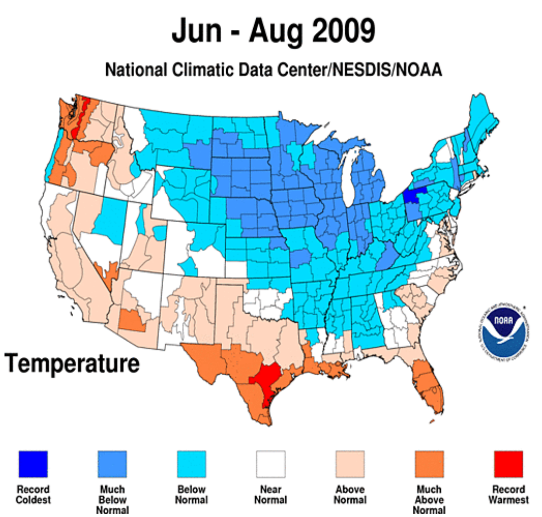

Summer AOD at 550-MODIS Aqua (Boone, NC)
AOD at 550nm
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
Year

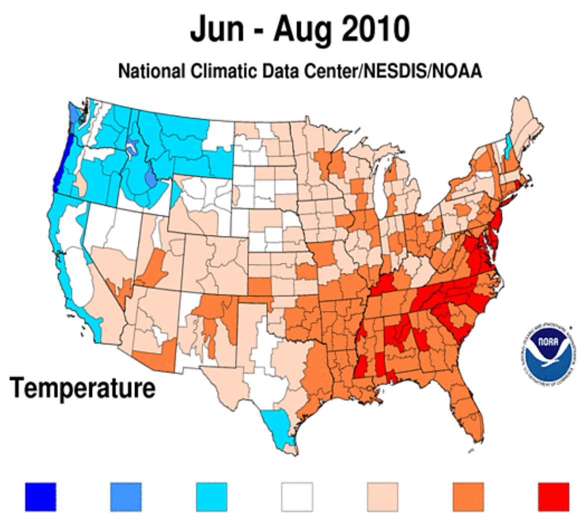
Summer Aerosol Loading and TOA DRF Variability (Boone)

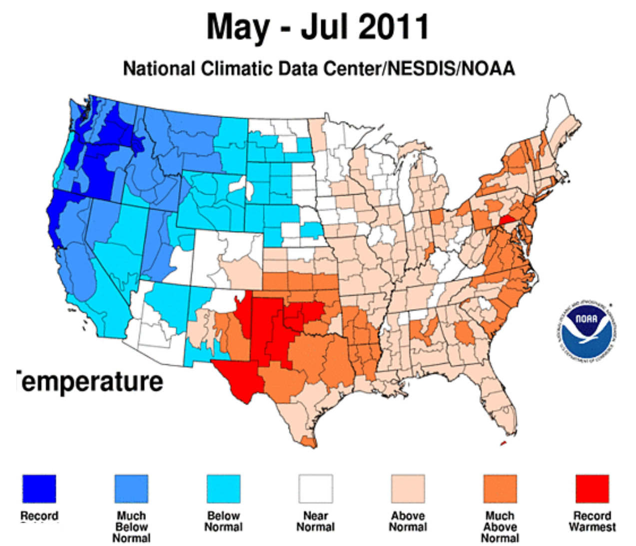


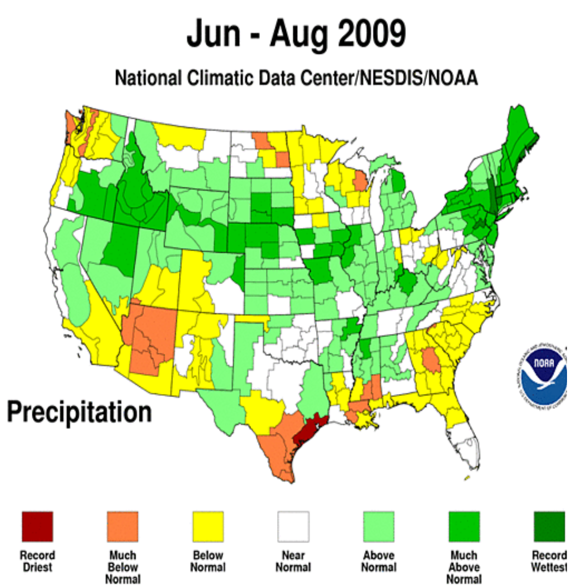


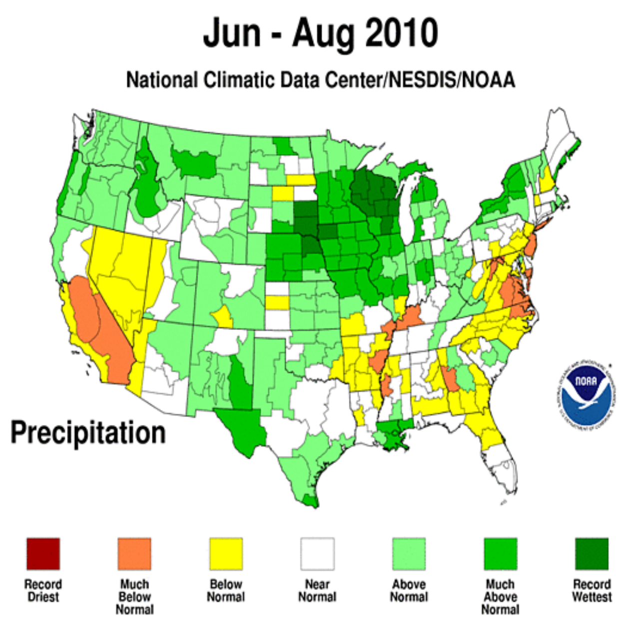
Summer Temperature and Precipitation Departures (2009-2011)

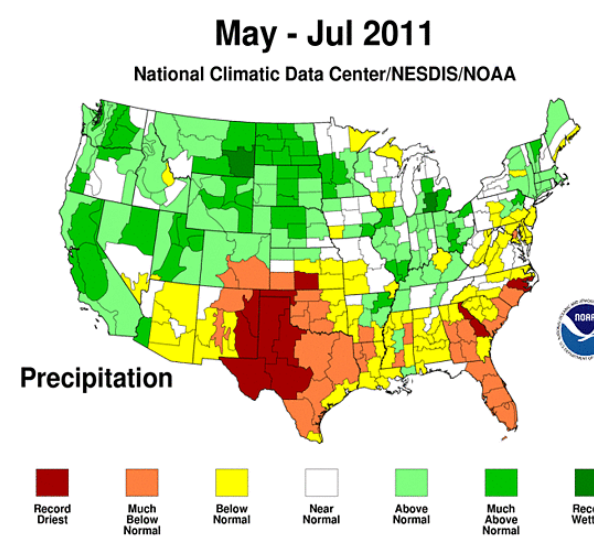






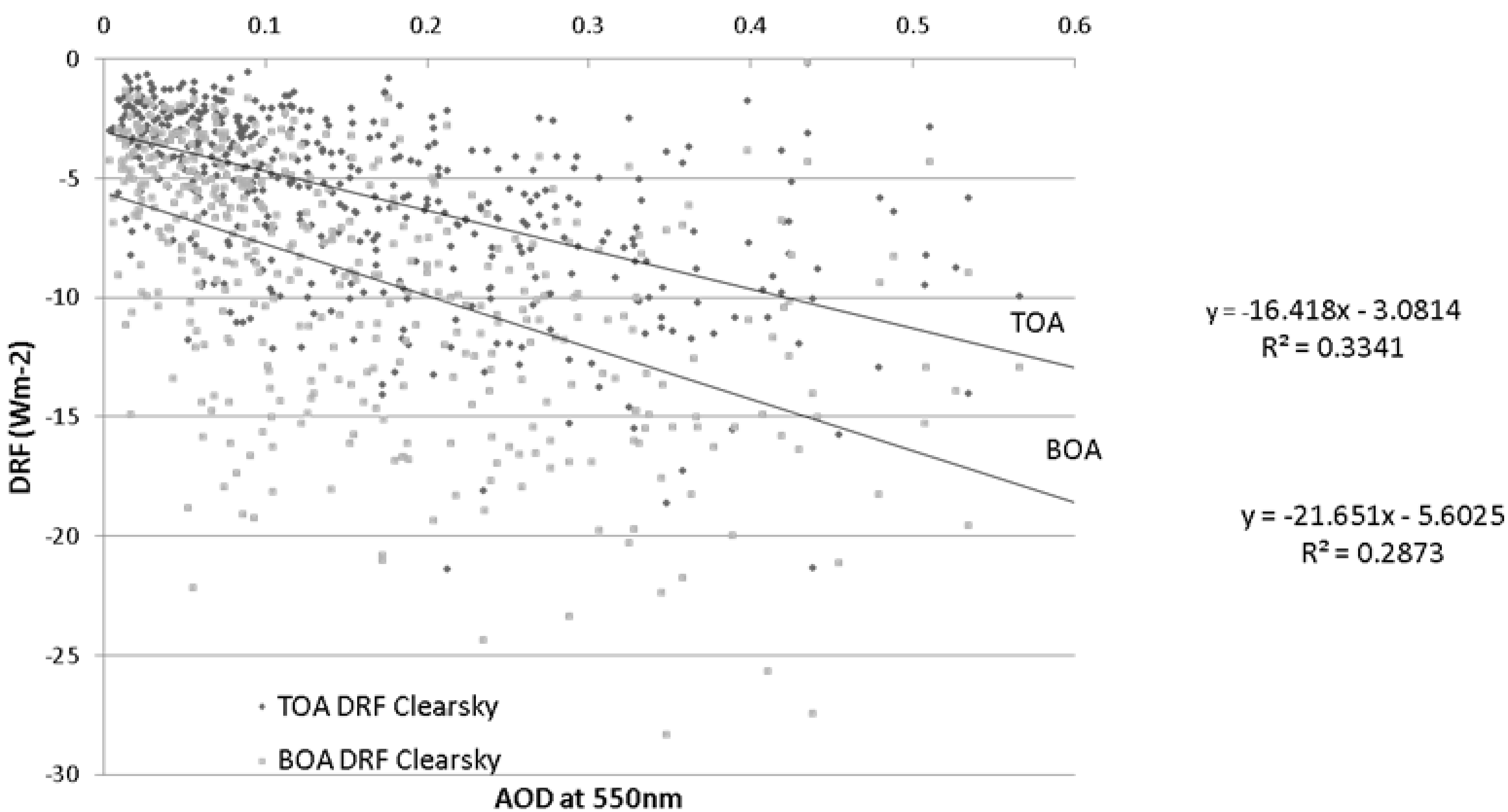


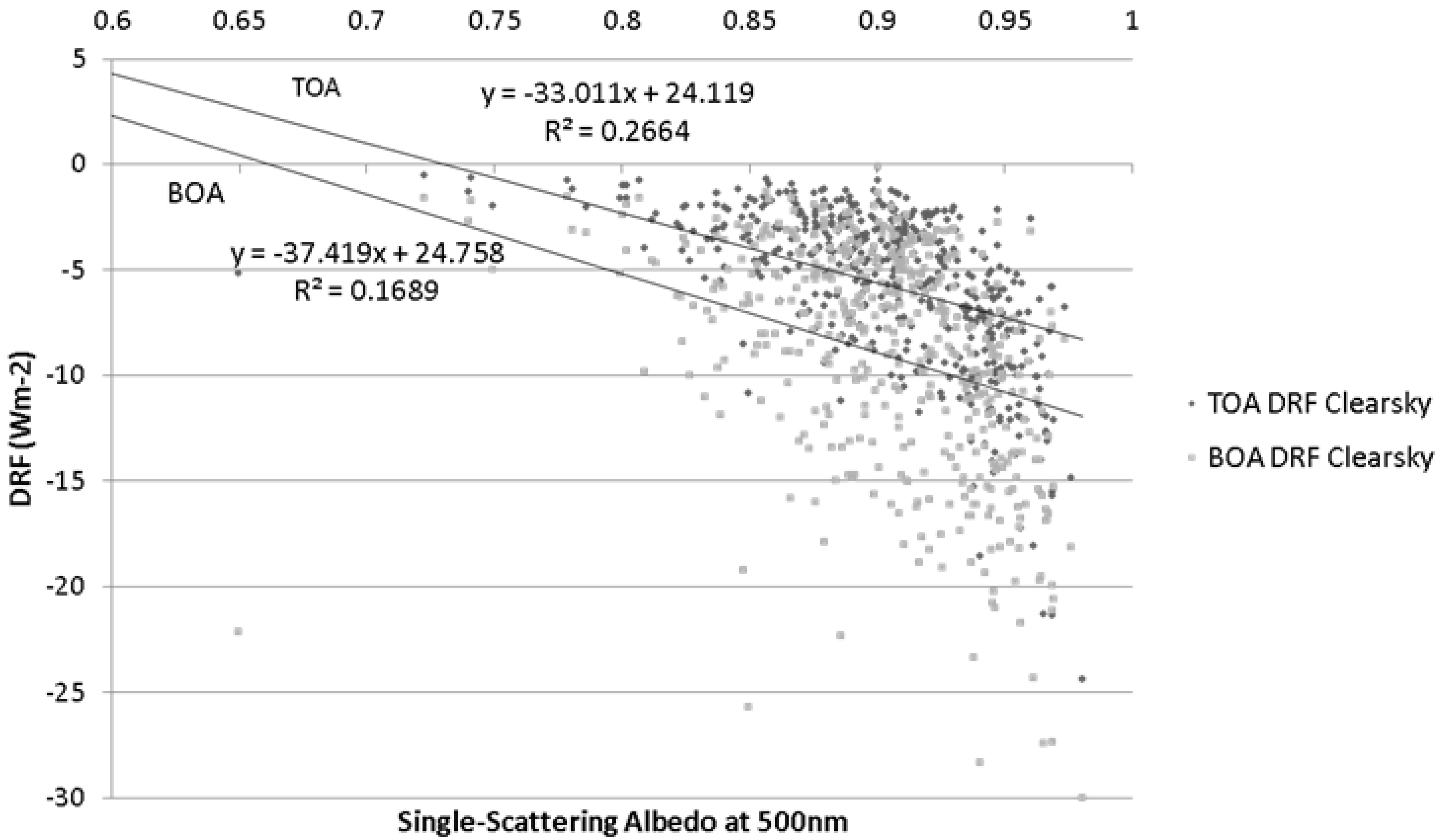




http://www.ncdc.noaa.gov/temp-and-precip/maps.php

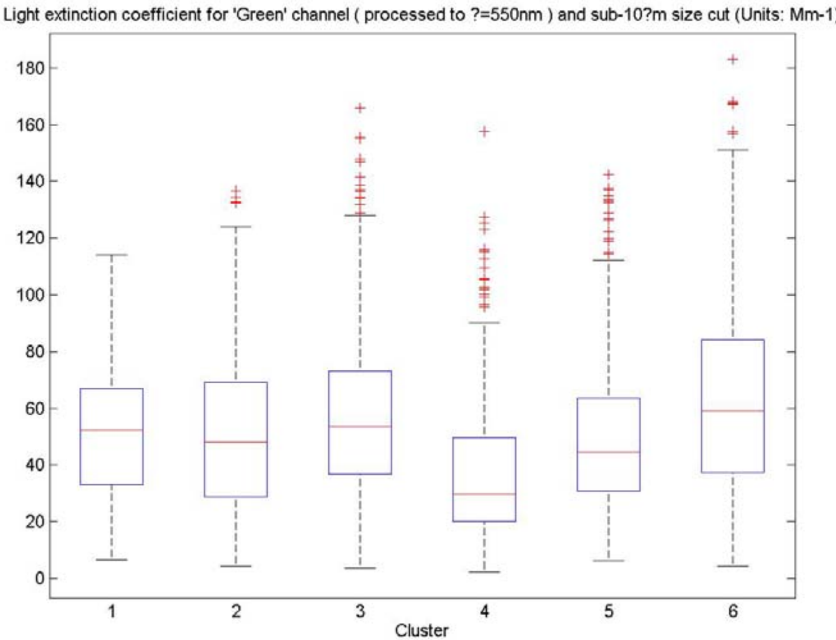
Correlation of DRF with SSA and AOD

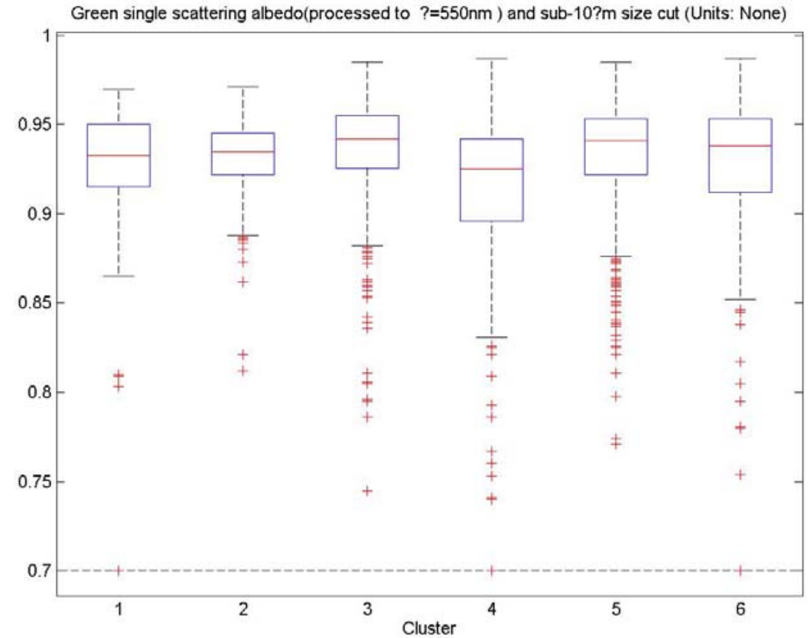




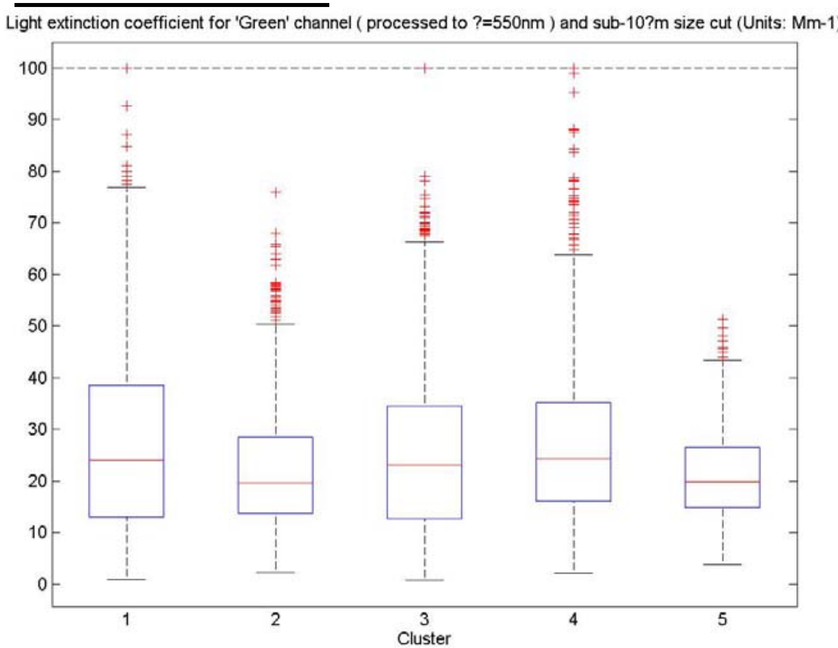
0.6
0.65
0.7
0.75
0.8
0.85
0.9
0.95
1
5
0
-5
-10
-15
-20
-25
-30
TOA
y = -33.011x + 24.119
R² = 0.2664
BOA
y = -37.419x + 24.758
R² = 0.1689
DRF (Wm-2)
Single-Scattering Albedo at 500nm
TOA DRF Clearsky
BOA DRF Clearsky

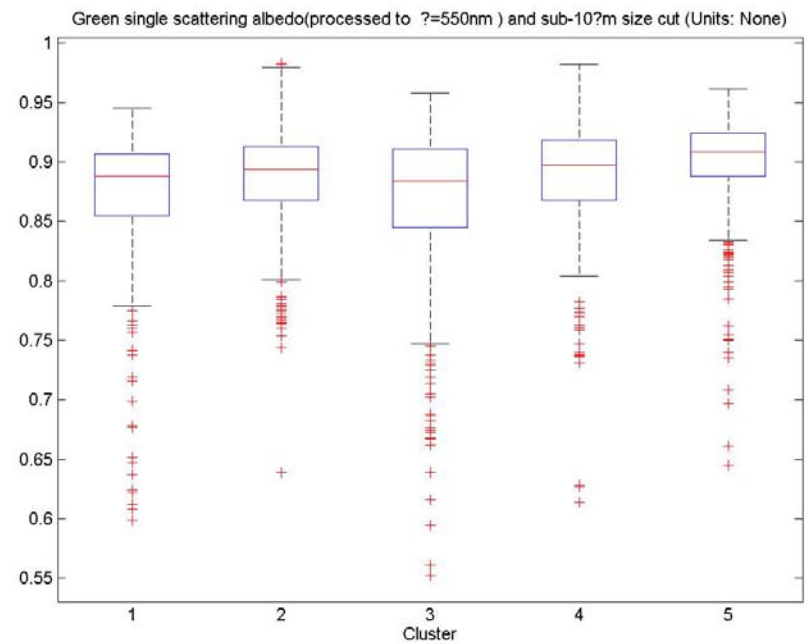
Warm Season

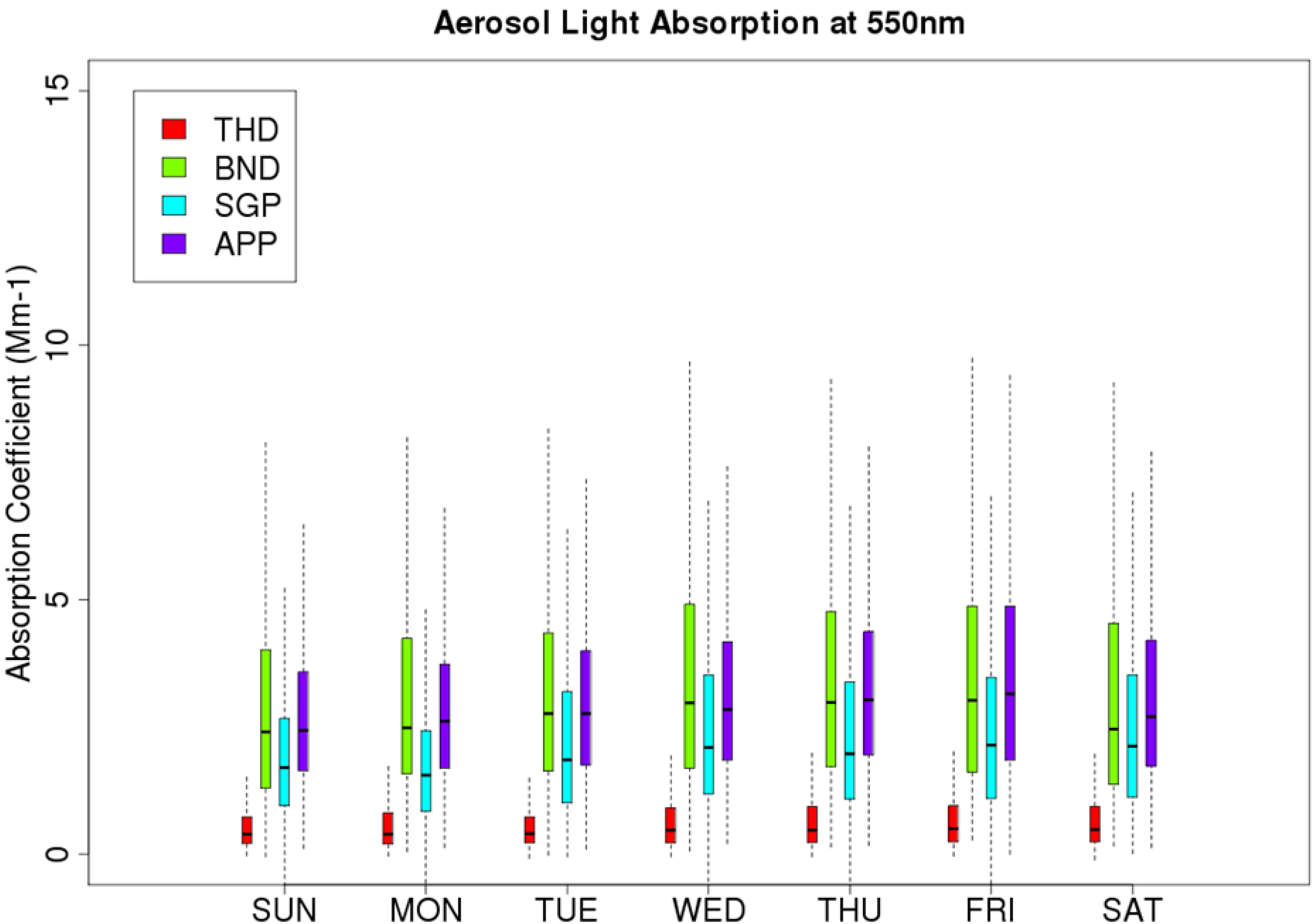




Cool Season



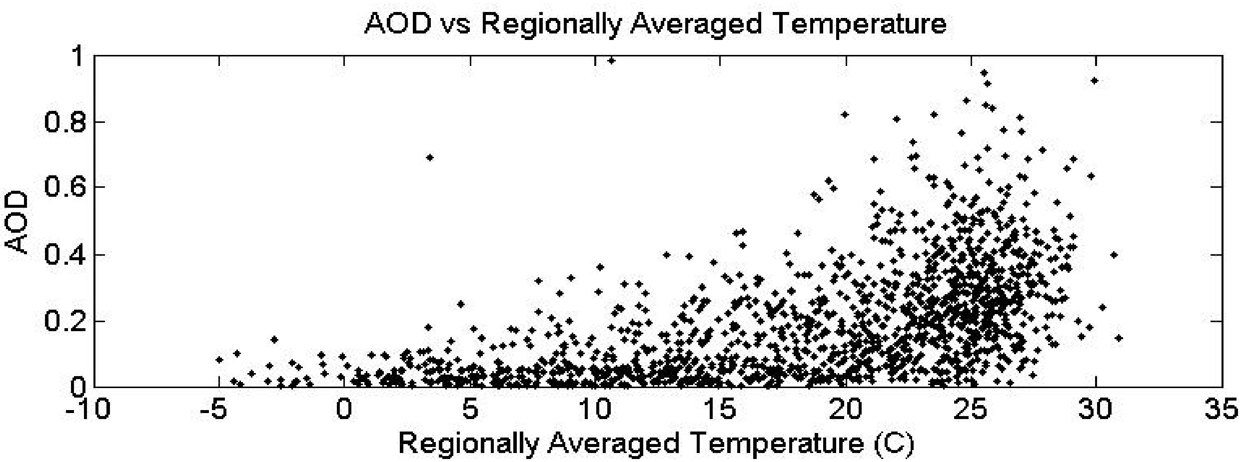


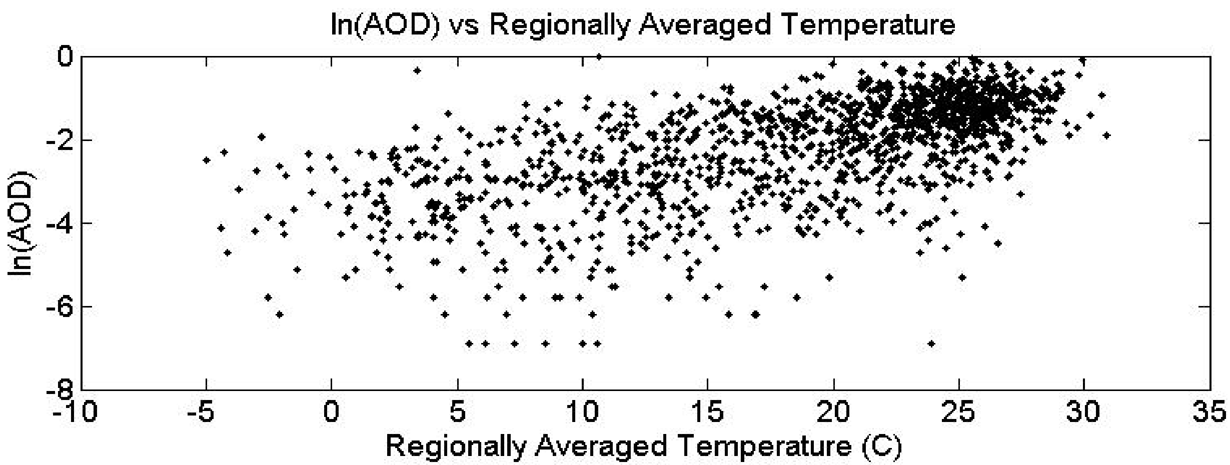


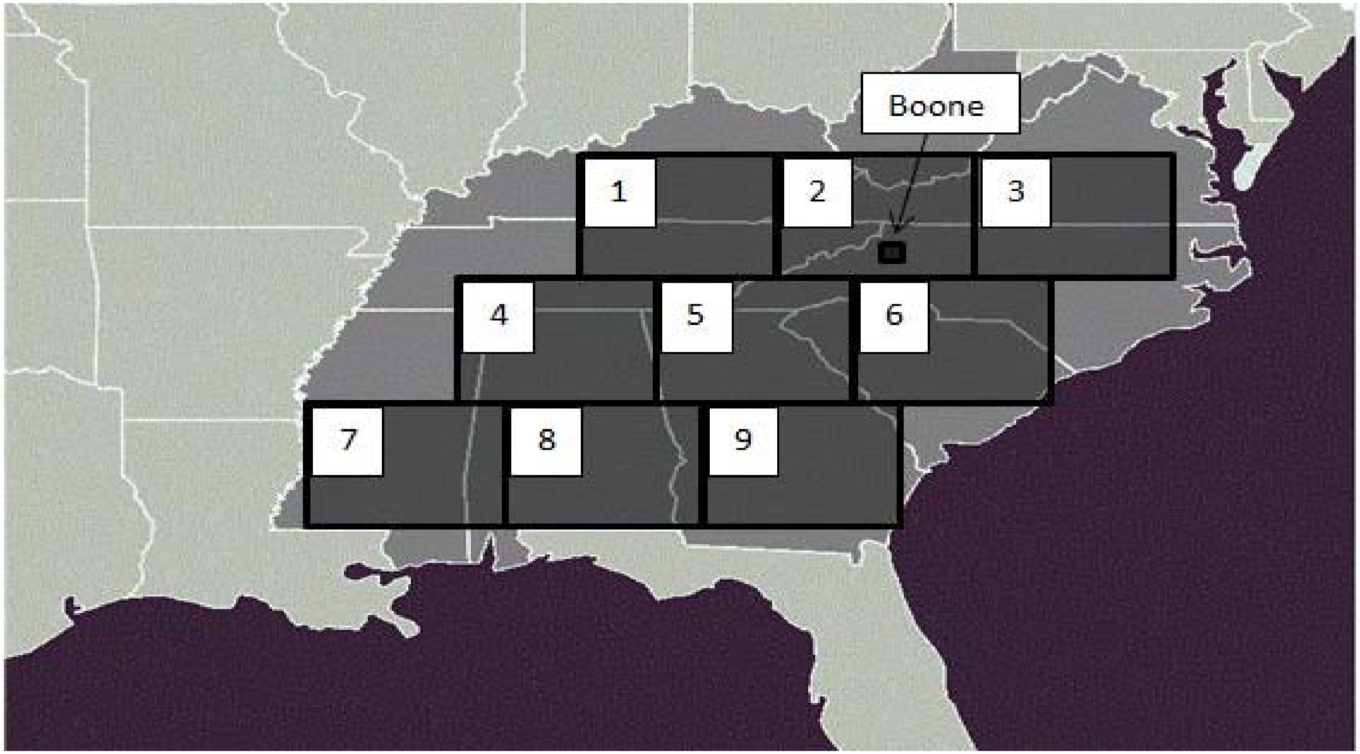
Aerosol Light Absorption at 550nm
Absorption Coefficient (Mm-1)
0
5
10
15
THD
BND
SGP
APP
SUN
MON
TUE
WED
THU
FRI
SAT

Estimate size of region over which column aerosols are representative

- Fit 9 years of MODIS Aqua AOD for each pixel to $AOD(T)= a*exp(b(T-T_0))$, assumed to be same as dependence of SOA precursors on temperature (Goldstein, 2009)
- Pixels would vary in loading (a) but similar relative influence of SOAs should yield similar b values and regression value







Pixel	Beta	Regression Value (R)
1	0.077	0.569
2	0.085	0.600
3	0.085	0.611
4	0.081	0.569
5	0.090	0.622
6	0.091	0.640
7	0.081	0.589
8	0.088	0.612
9	0.088	0.617
Boone	0.097	0.603

Seasonal Variability in Lower Tropospheric Aerosol Optical Properties (June 2009-April 2012)

- Note: These initial studies did not account for RH-dependence on light scattering