Initial Study of the Roles of Chemical Composition and Meteorology on Aerosol Radiative Effects in the SE U.S.- Results from a Regionally-Representative Site

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Appalachian State University

Outline

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Motivation for Aerosol Research in SE U.S.

APP Monitoring Site

II. Relationships between aerosol optical properties and chemical composition

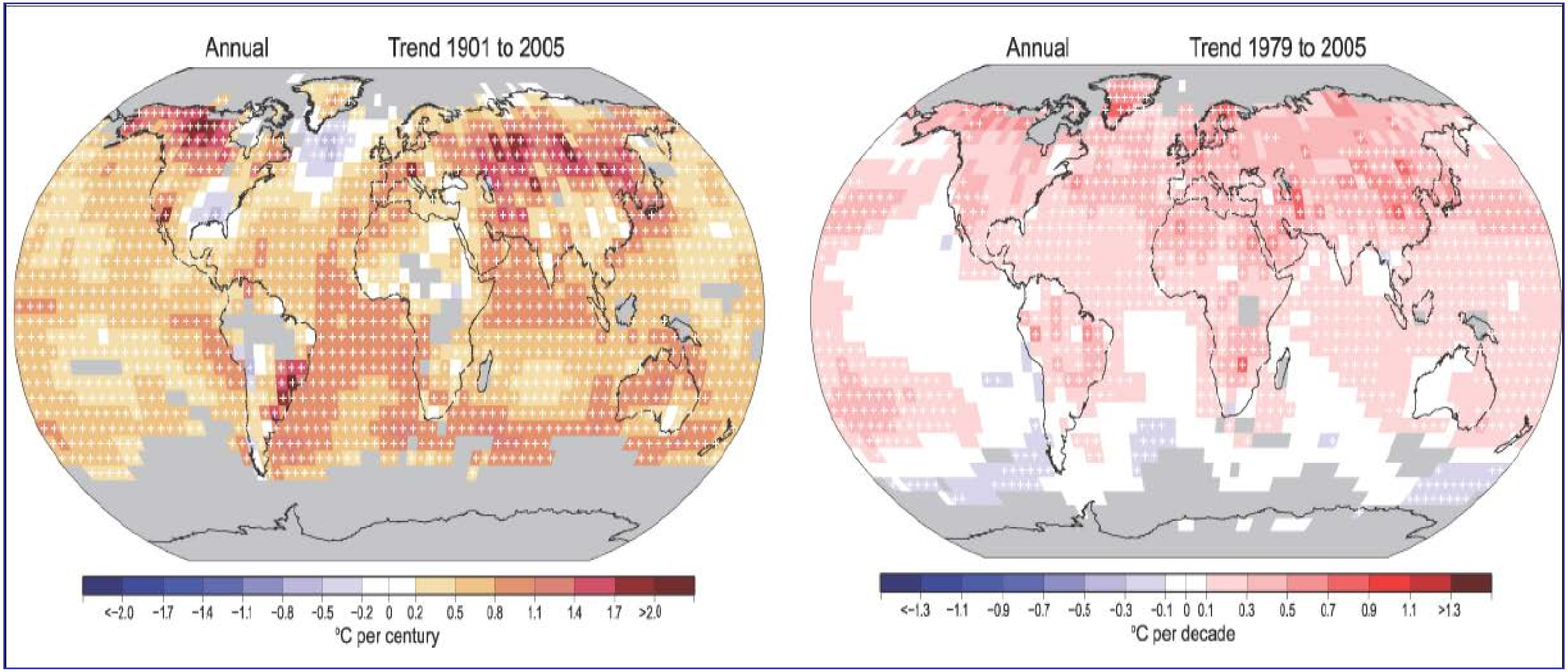
III. Dependence of aerosol properties on meteorology and source region

IV. Conclusions

V. Appendices

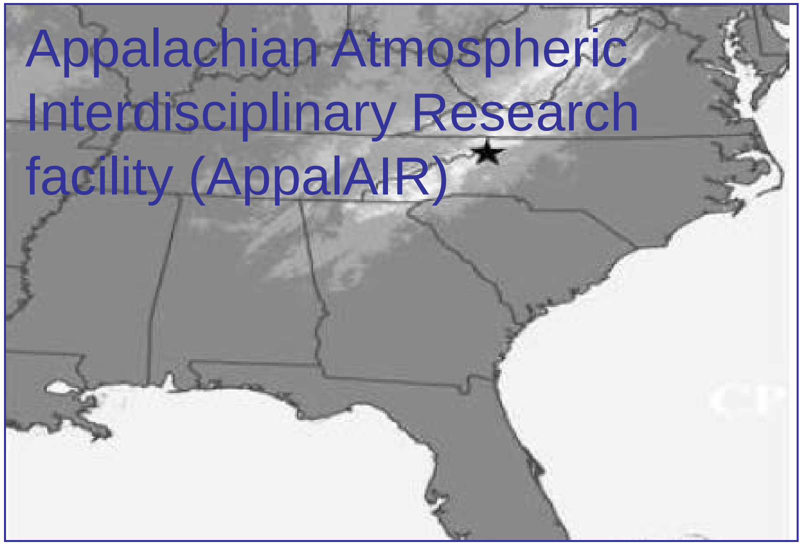
A. Time series of aerosol properties

Introduction



Trenberth, et al., 2007

Southeastern US: one of a few regions in world not to have warmed in 20th century, but is beginning to warm in recent decades



Boone, NC, 36.2° N, 81.7° W, 1076 m

Tower height 34 m

NASA - AERONET aerosol monitoring site

NOAA-ESRL aerosol monitoring site

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Data products	Measurement techniques
Aerosol light absorption at 467 nm, 530 nm, 660 nm wavelengths (size-resolved, sub-μm, sub-10 μm)	Radiance Research Particle Soot Absorption Photometer (PSAP)
Aerosol total light scattering and hemispheric backscattering at 450 nm, 550 nm, and 700 nm (size-resolved, sub-μm, sub-10 μm)	TSI 3563 Nephelometer
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 number concentration	TSI 3010 Condensation Particle Counter (CPC)
Aerosol size distributions	CIMEL 318 Solar-Tracking Sun/Sky Radiometer
Spectral aerosol optical depth (AOD) at eight wavelengths between 340-1020 nm)	
Aerosol chemical composition (size-resolved, sub- μm)	Aerodyne Aerosol Mass Spectrometer (AMS)

Initial Studies of Relationships between Aerosol Radiative Properties, Aerosol Chemistry, Meteorology, and Source Region

- Lower tropospheric aerosol properties have been measured continuously since June 2009
- Column-averaged and vertically-resolved aerosol properties have been measured near-continuously since August 2010 and April 2011, respectively
- This initial study will focus on a 7-week period (June 4-July 21, 2012), when the aerosol chemical composition measurements were initiated. This period will be referred to as ‘Summer 2012’ in the presentation
- The upcoming summer 2013 field campaign and subsequent measurements will provide opportunity to expand upon this study

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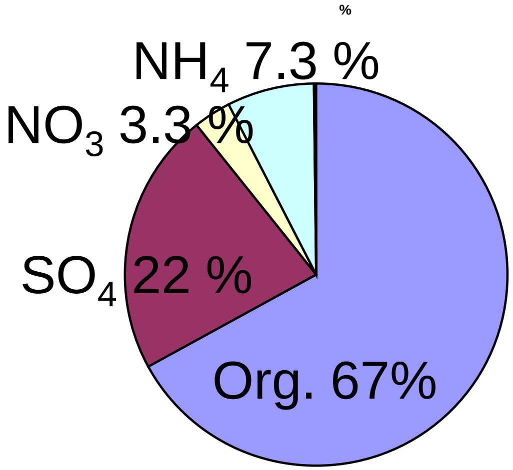
Summer 2012 statistics of non-refractory aerosol chemical composition

	NH_4 (μg/m^3)	NO_3 (μg/m^3)	SO_4 (μg/m^3)	Org (μg/m^3)	Chl (μg/m^3)	Total* (μg/m^3)
Mean	0.181	0.076	0.557	1.627	0.006	2.447
Stdev	0.112	0.039	0.379	0.833	0.003	1.217

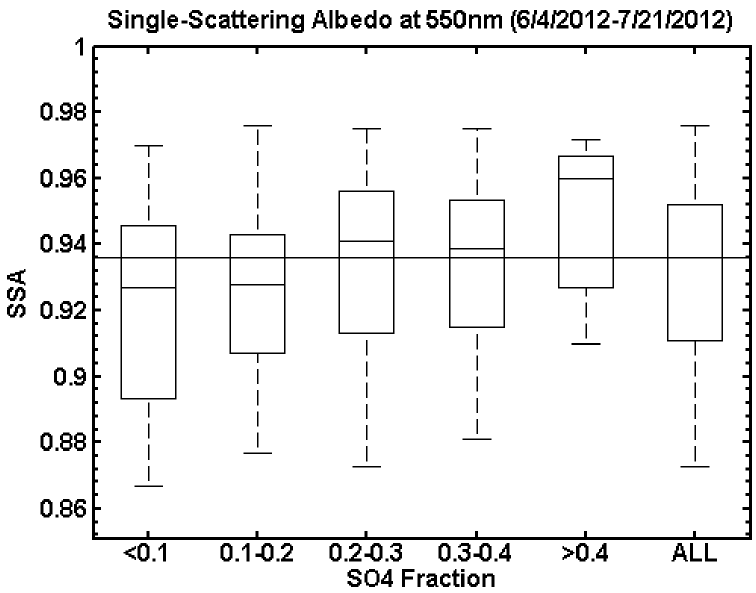
* Total mass loading refers to the sum of NH_4, NO_3, SO_4, Org and Chl



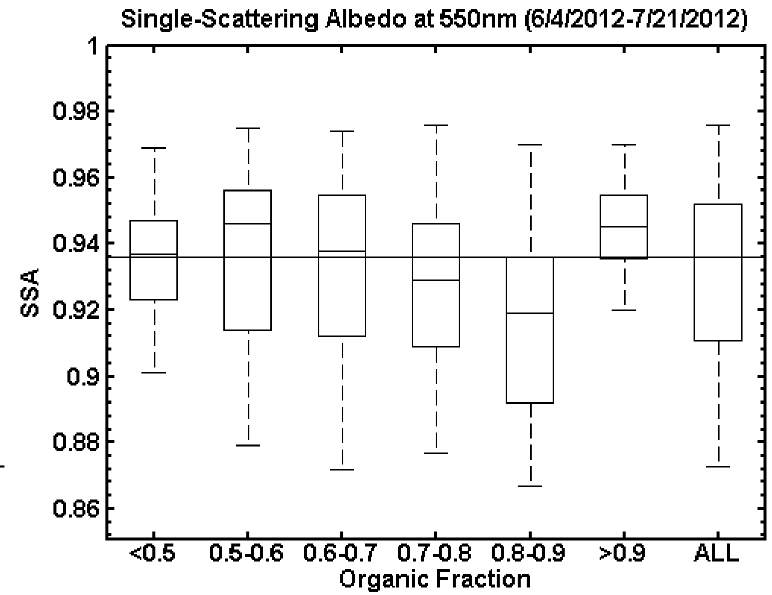
Ammonium sulfate: ~7.5 μg/m^3, Particle organic matter: ~ 4.0 μg/m^3 IMPROVE 2005-2008 regional monthly mean $PM_{2.5}$ in June in Southern Appalachian mountain region) [*Hand et al.,* 2012]

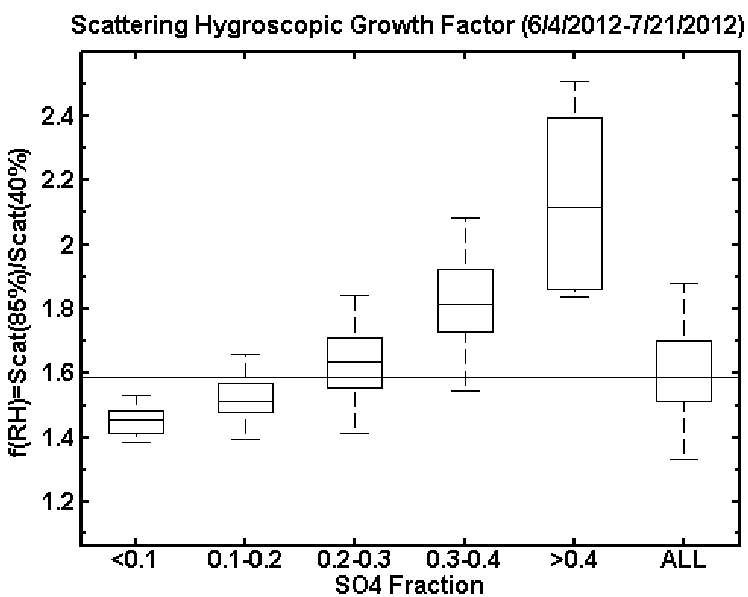
$(NH_4)SO_4$: 54% Org.: 36% in $PM_{2.5}$ in summer at rural sites in southeastern US. (*Zhang et al.,* 2012)

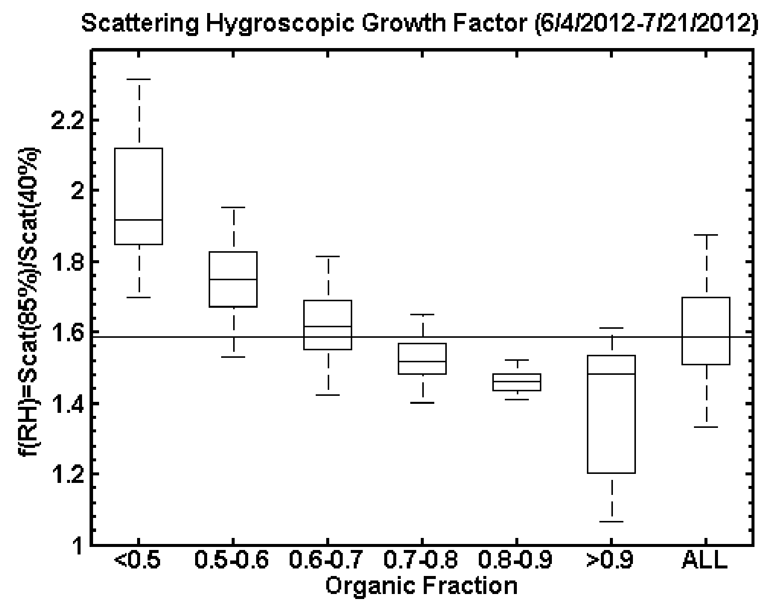
Chemical composition relationships



$$\omega_o = \frac{\sigma_{sp}}{\sigma_{sp} + \sigma_{ap}}$$



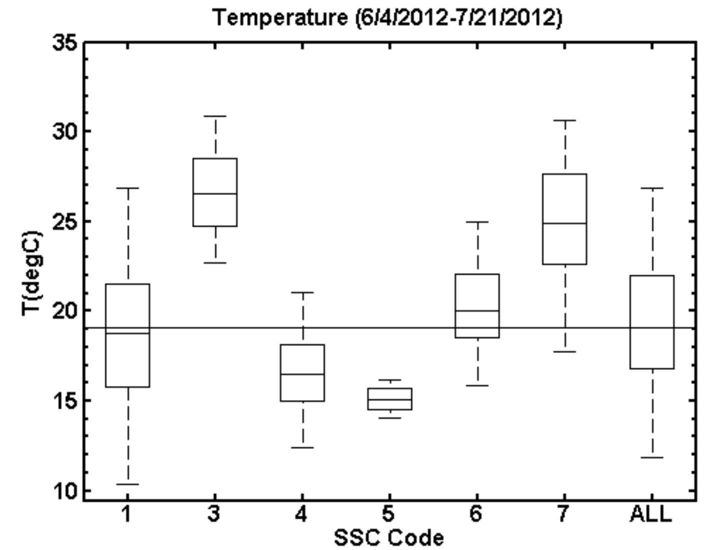


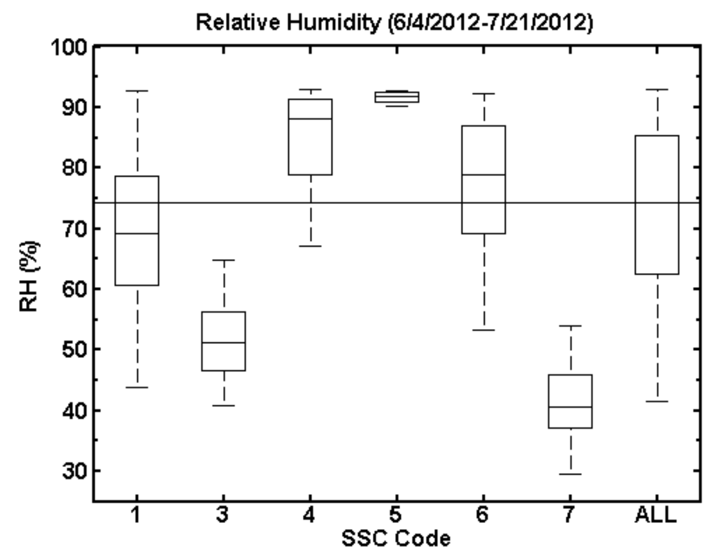


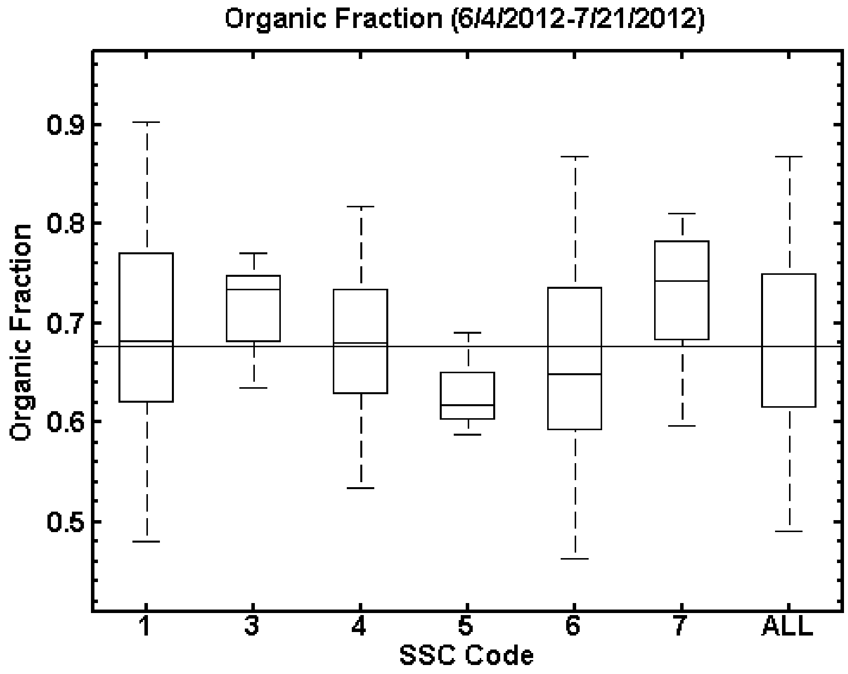
Dependence of aerosol properties on synoptic meteorology

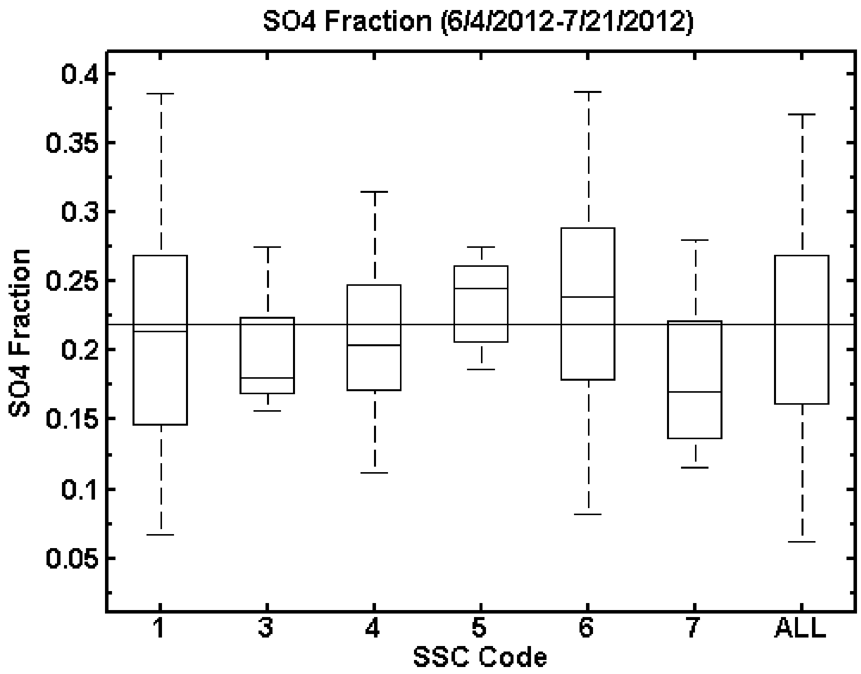
- Synoptic-scale meteorological classification (SSC) scheme of Power and Sheridan (2006)

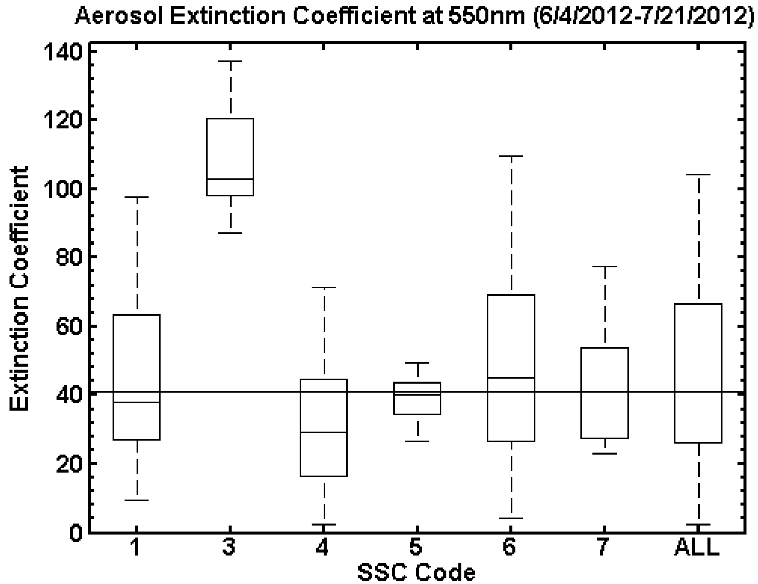
SSC Code	Type	# Hours	% Hours
1	Dry Moderate	483	42%
2	Dry Polar	0	0%
3	Dry Tropical	48	4.2%
4	Moist Moderate	168	14.6%
5	Moist Polar	24	2.1%
6	Moist Tropical	380	33%
7	Transition or Missing Data	48	4.2%

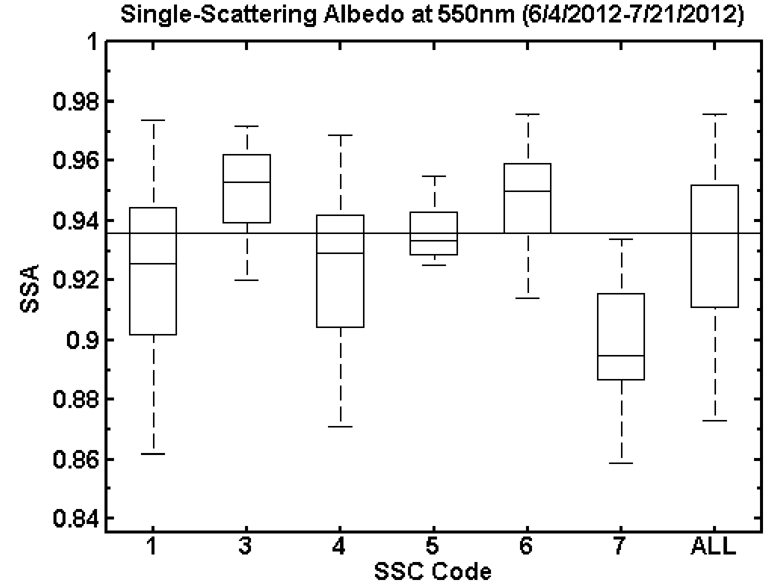




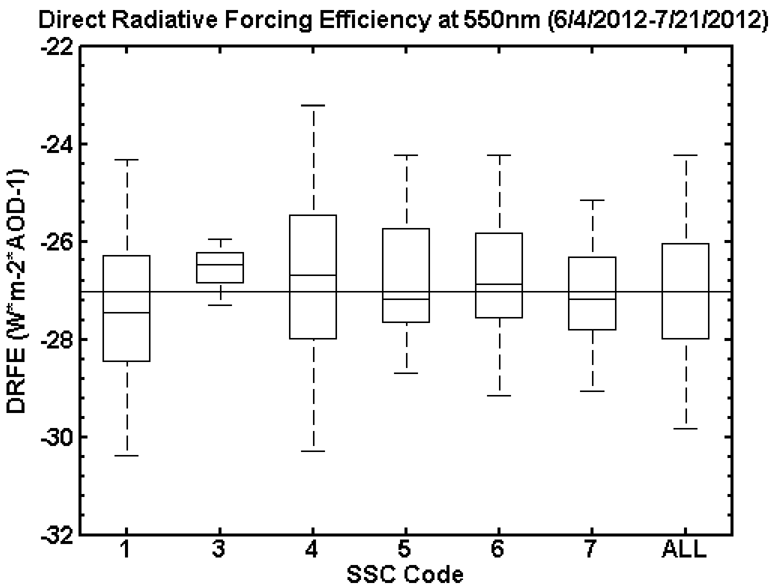

Organic Fraction (6/4/2012-7/21/2012)
Organic Fraction
0.9
0.8
0.7
0.6
0.5
1
3
4
5
6
7
ALL
SSC Code

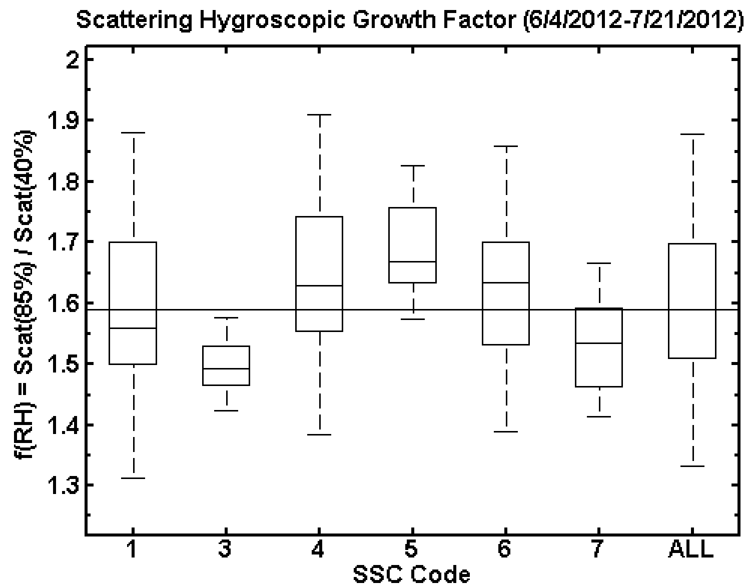

SO4 Fraction (6/4/2012-7/21/2012)
SO4 Fraction
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
1
3
4
5
6
7
ALL
SSC Code





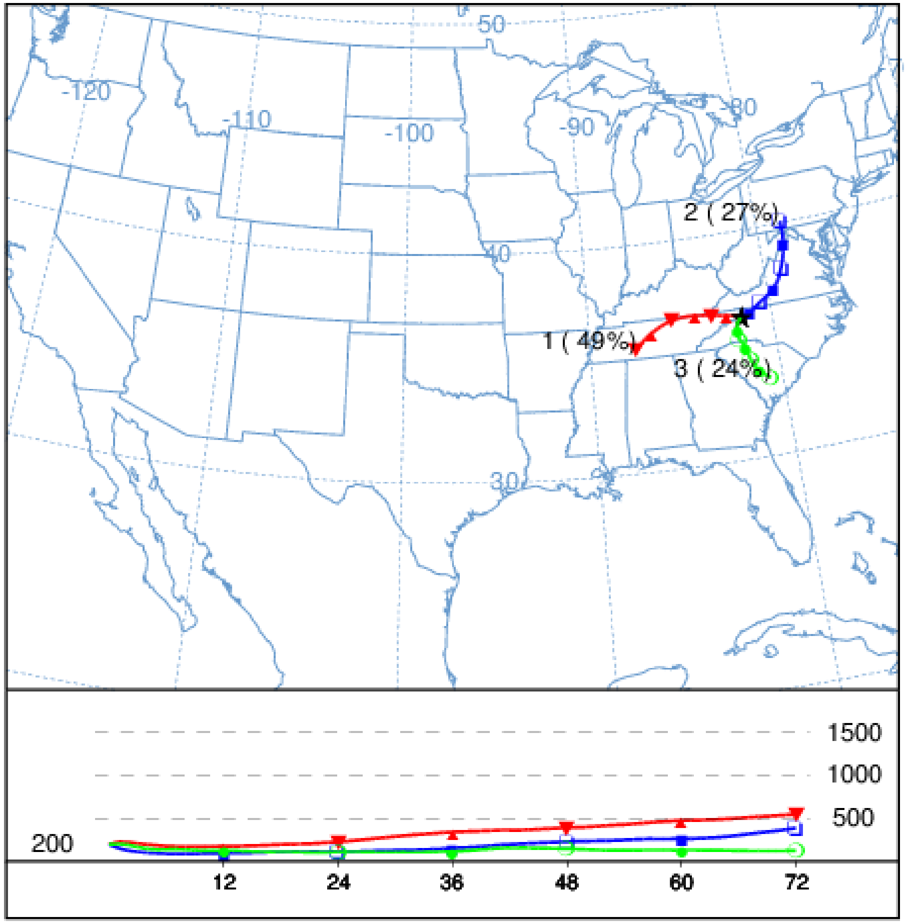
$\sigma_{ext} = \sigma_{sp} + \sigma_{ap}$

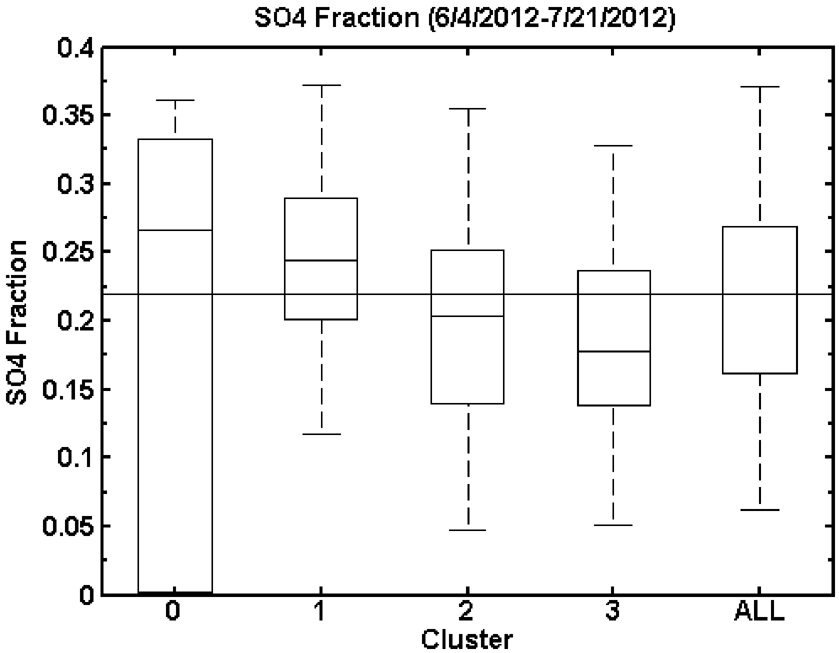


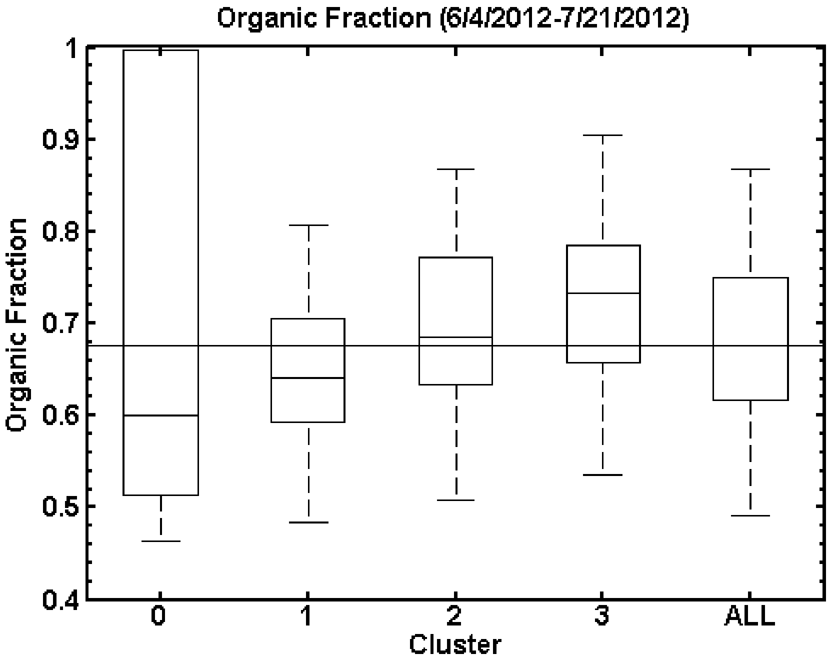


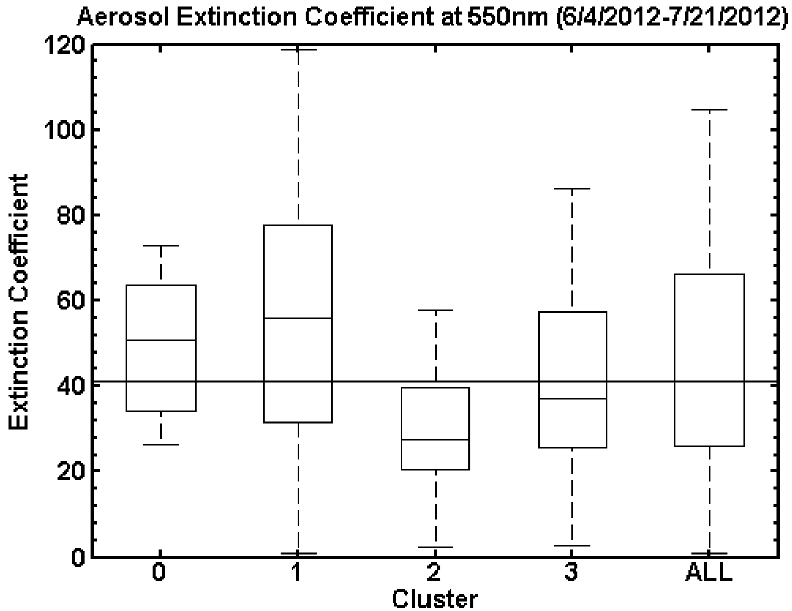
Dependence of aerosol properties on source region

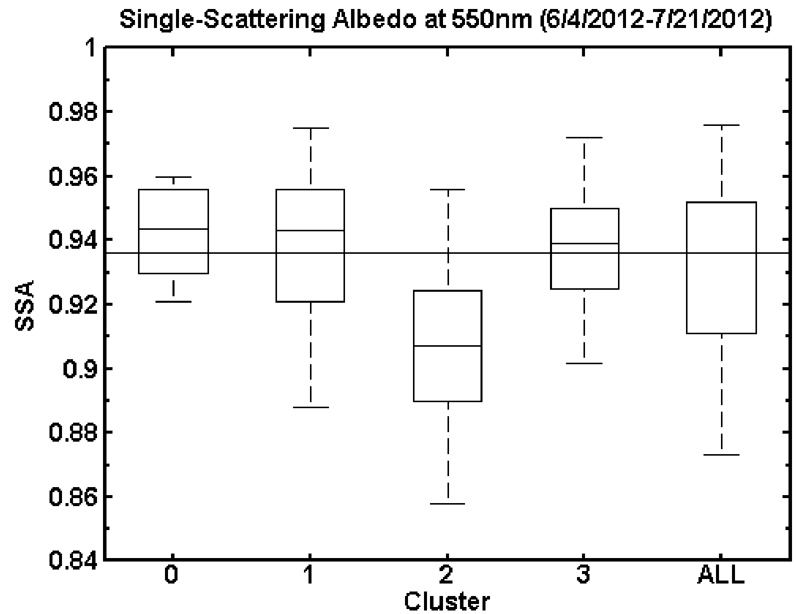
Source Region Code	Type	# Hours	% Hours
0	Back trajectories did not clustered	483	
1	Long range transport from West/Southwest	0	49%
2	Long range transport from north	48	27%
3	Southeast/local	168	24%

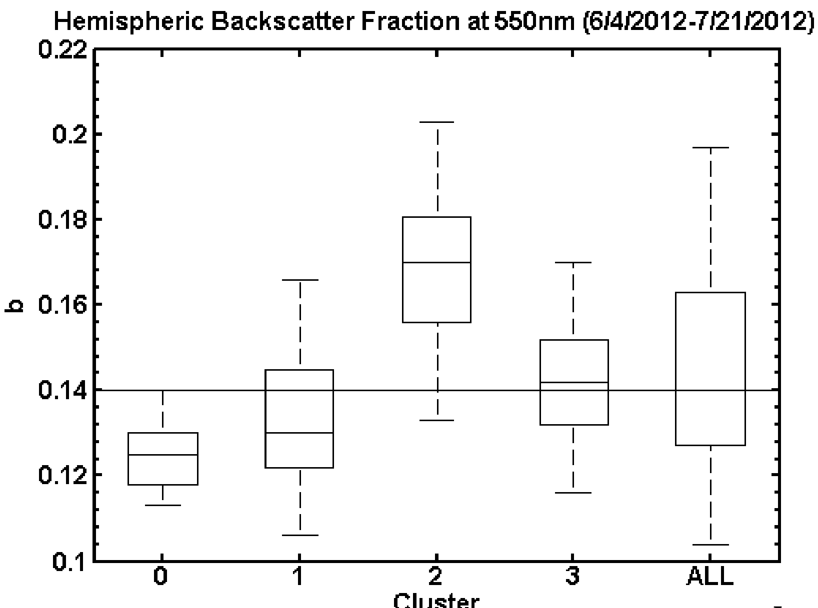


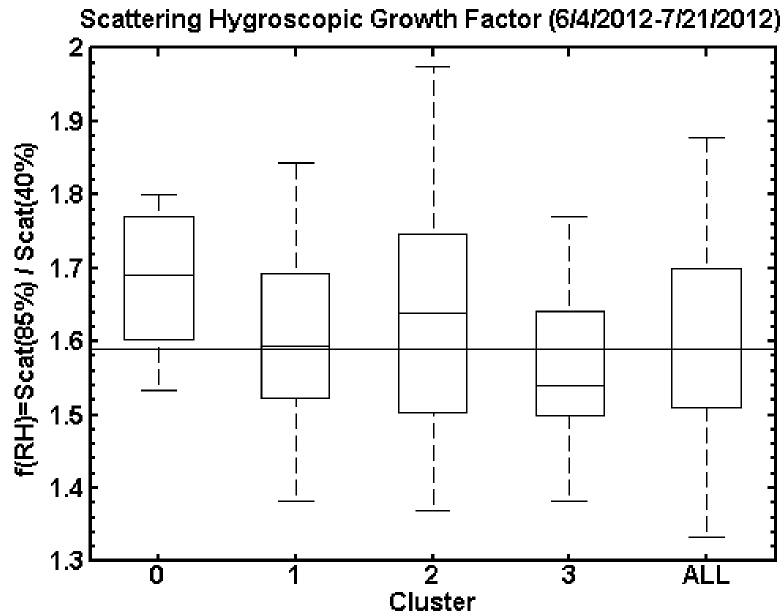

SO4 Fraction (6/4/2012-7/21/2012)
SO4 Fraction
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
1
2
3
ALL
Cluster


Organic Fraction (6/4/2012-7/21/2012)
Organic Fraction
1
0.9
0.8
0.7
0.6
0.5
0.4
0
1
2
3
ALL
Cluster









$$b = \frac{\sigma_{bsp}}{\sigma_{sp}}$$

Conclusions

- Organics dominated the non-refractory aerosol mass loading during the summer 2012 period, consistent with other recent studies in the region (Goldstein, 2008).
- Aerosol single scattering albedo and hygroscopic growth factor increased with sulfate fraction. Aerosol hygroscopic growth factor decreased with increased organic fraction.
- Aerosol organic fraction, mass loading and extinction coefficient increased with ambient temperature due to the increased photochemical formation of secondary organic aerosol and highly temperature-dependent BVOC emissions from forests.
- Aerosol originating in the SE U.S. (local) had relatively high organic fraction consistent with the forested and rural environment. Aerosol transported from the west and southwest corresponded to high sulphate fraction. Aerosol transported from the north had anthropogenic influences with relatively lower single scattering albedo.
- The results are based on ~7 week measurements. Long term observations are needed to improve the understanding of the relationships among aerosol properties, source and meteorology.

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John Markham

ASU Faculty
Brett Taubman

ASU Staff
Mike Hughes
Dana Green
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Brent Holben (NASA AERONET)

AMS community
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HYSPLIT model
Air Resources Laboratory (NOAA)

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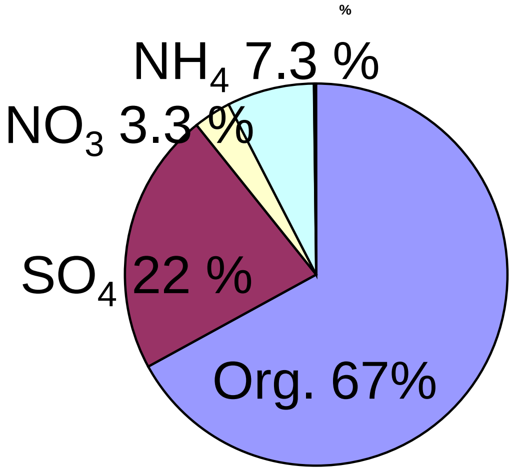
Stdev	0.112	0.039	0.379	0.833	0.003	1.217

* Total mass loading refers to the sum of NH_4, NO_3, SO_4, Org and Chl



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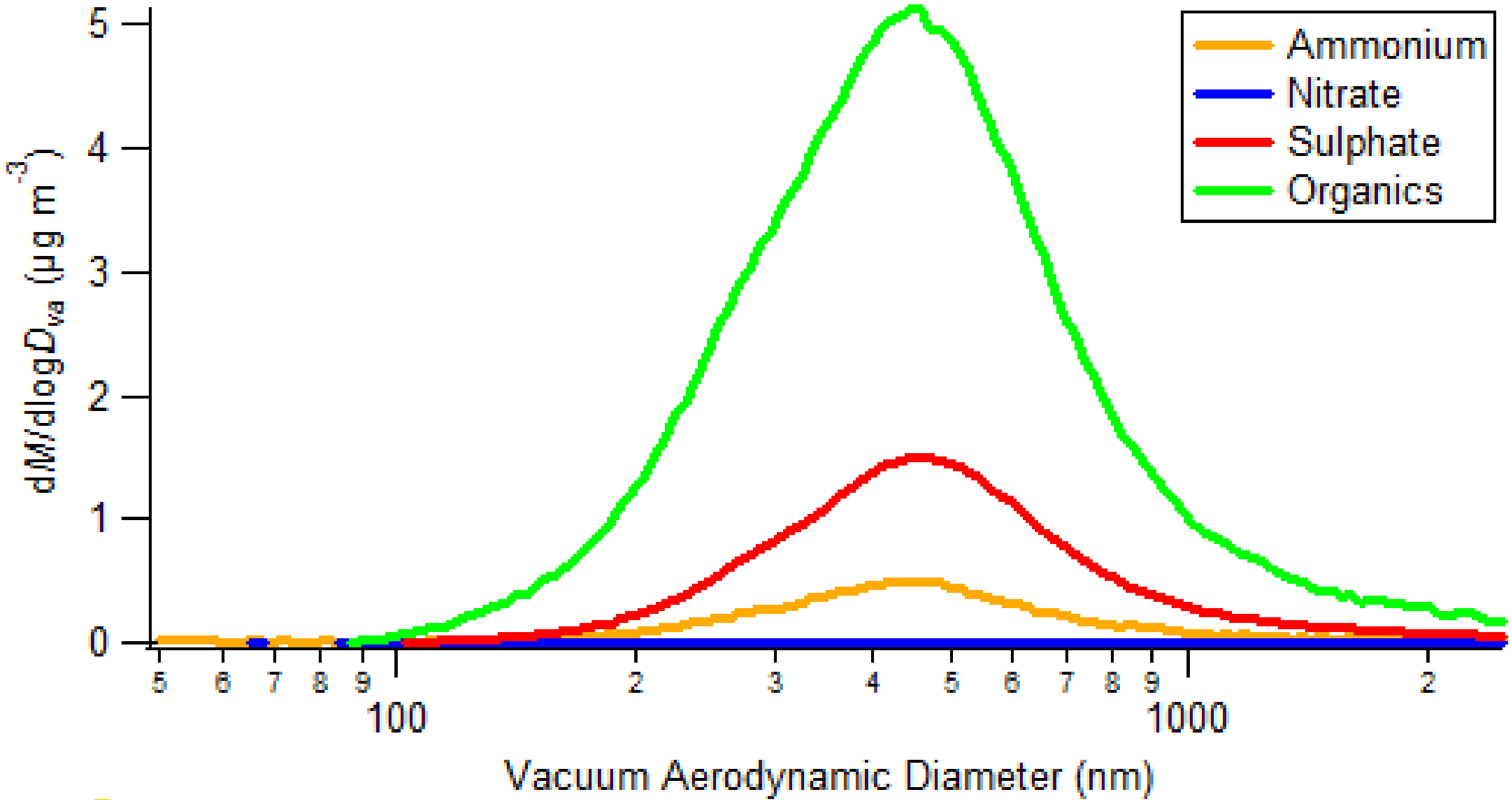
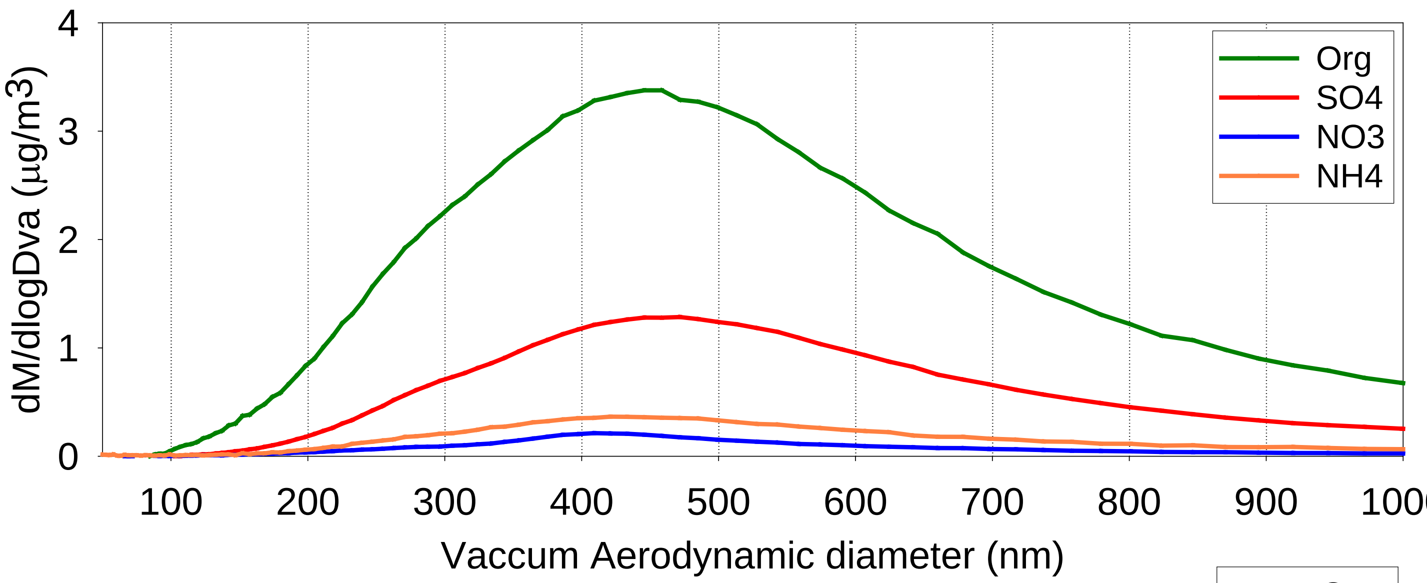
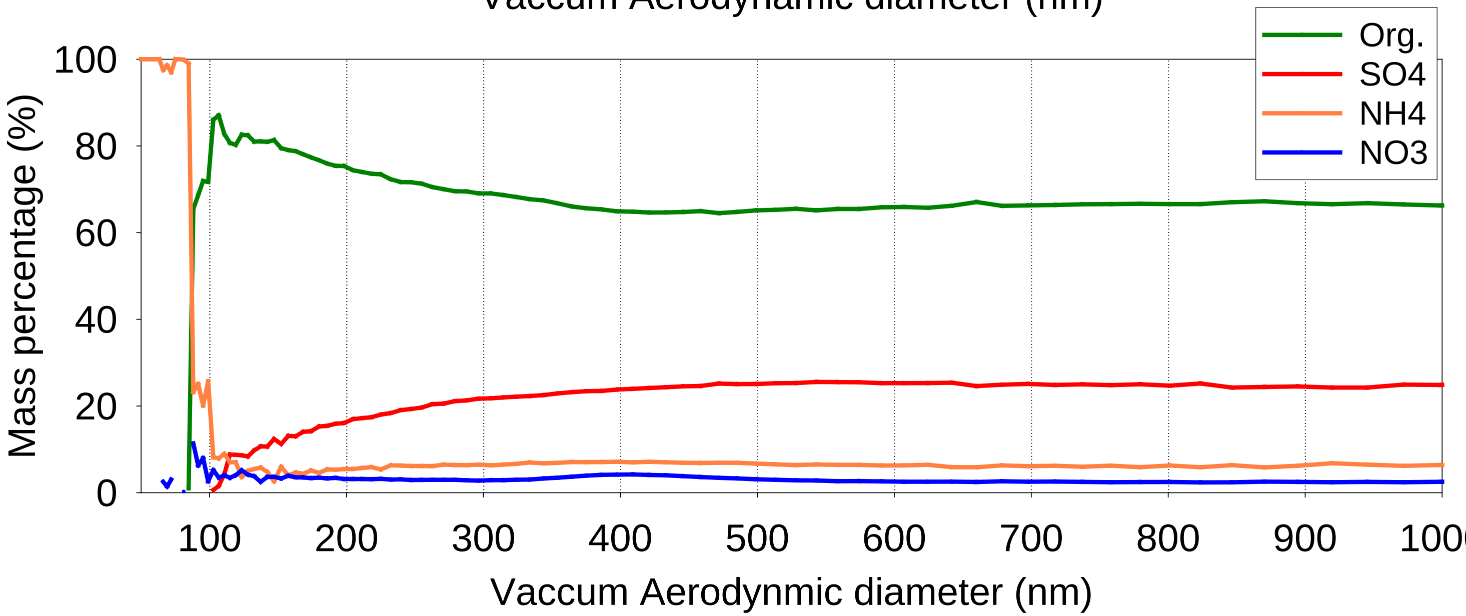

Ammonium
Nitrate
Sulphate
Organics
$dM/d\log D_{va}$ ($\mu g\ m^{-3}$)
0
1
2
3
4
5
5
6
7
8
9
100
2
3
4
5
6
7
8
9
1000
2
Vacuum Aerodynamic Diameter (nm)

Summer 2012 non-refractory aerosol size distribution





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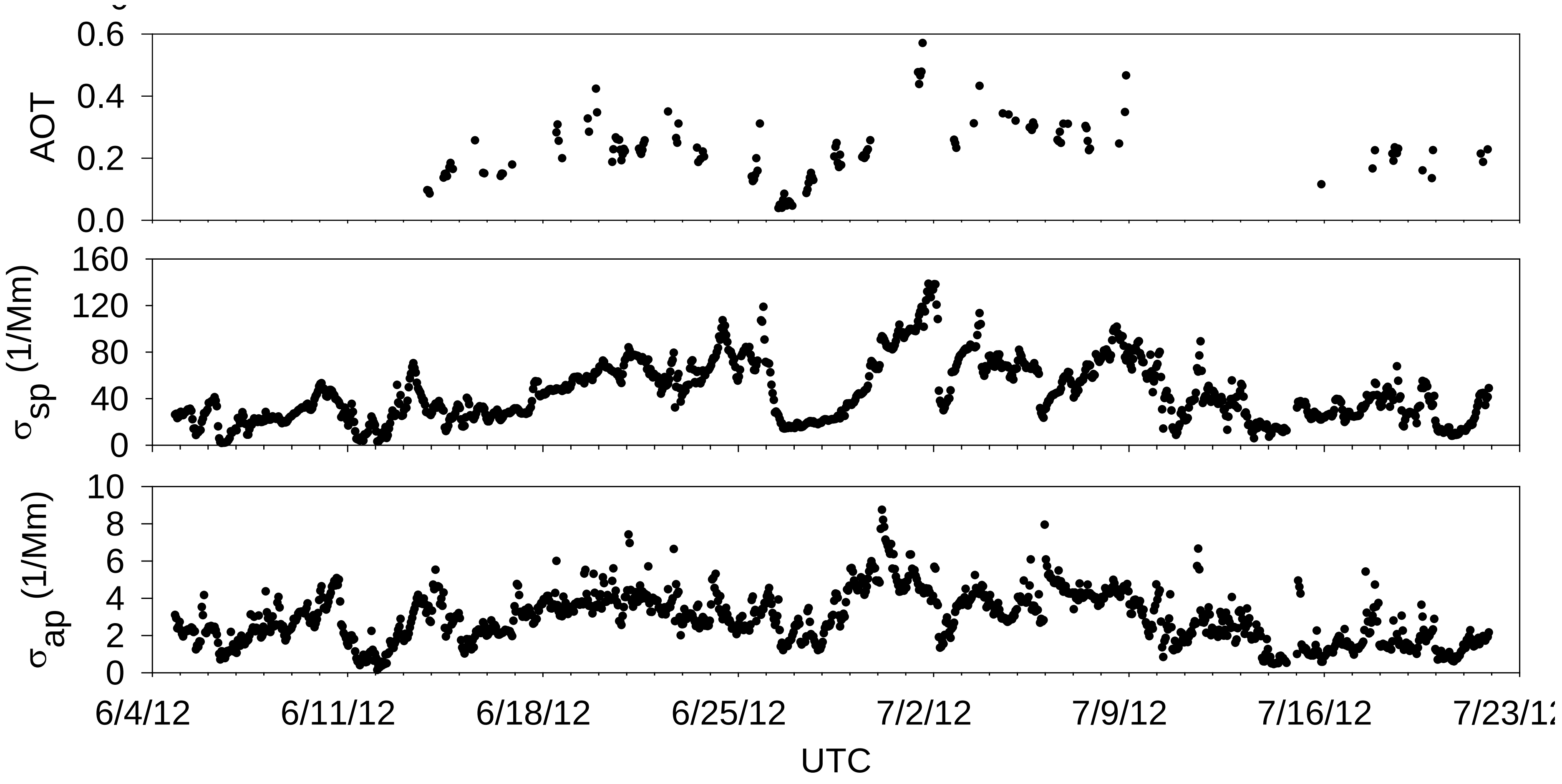
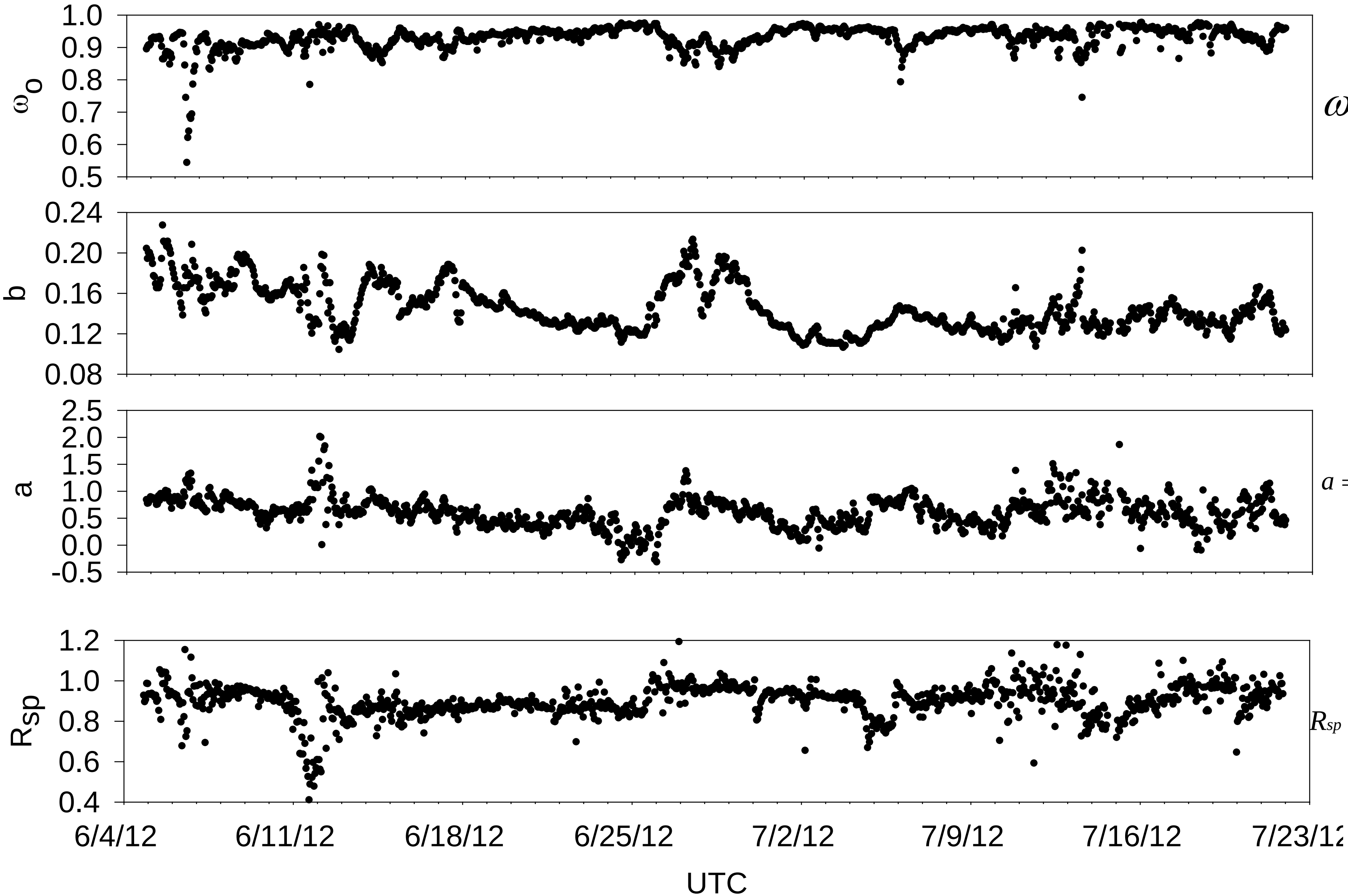
D_{va} = D_physical x density x shape factor

Figure 1: Summer 2012 time serials of total non-refractory aerosol mass loading (AMS μm/m³), aerosol optical thickness (AOT) at 500 nm, and sub-10μm aerosol scattering (σ_{sp}) and absorption (σ_{ap}) at 550 nm



Summer 2012 time serials of single-scattering albedo (ω_0), back-scatter fraction (*b*) at 550 nm, Angstrom exponent (a) and sub-1um scattering fraction (R sp)



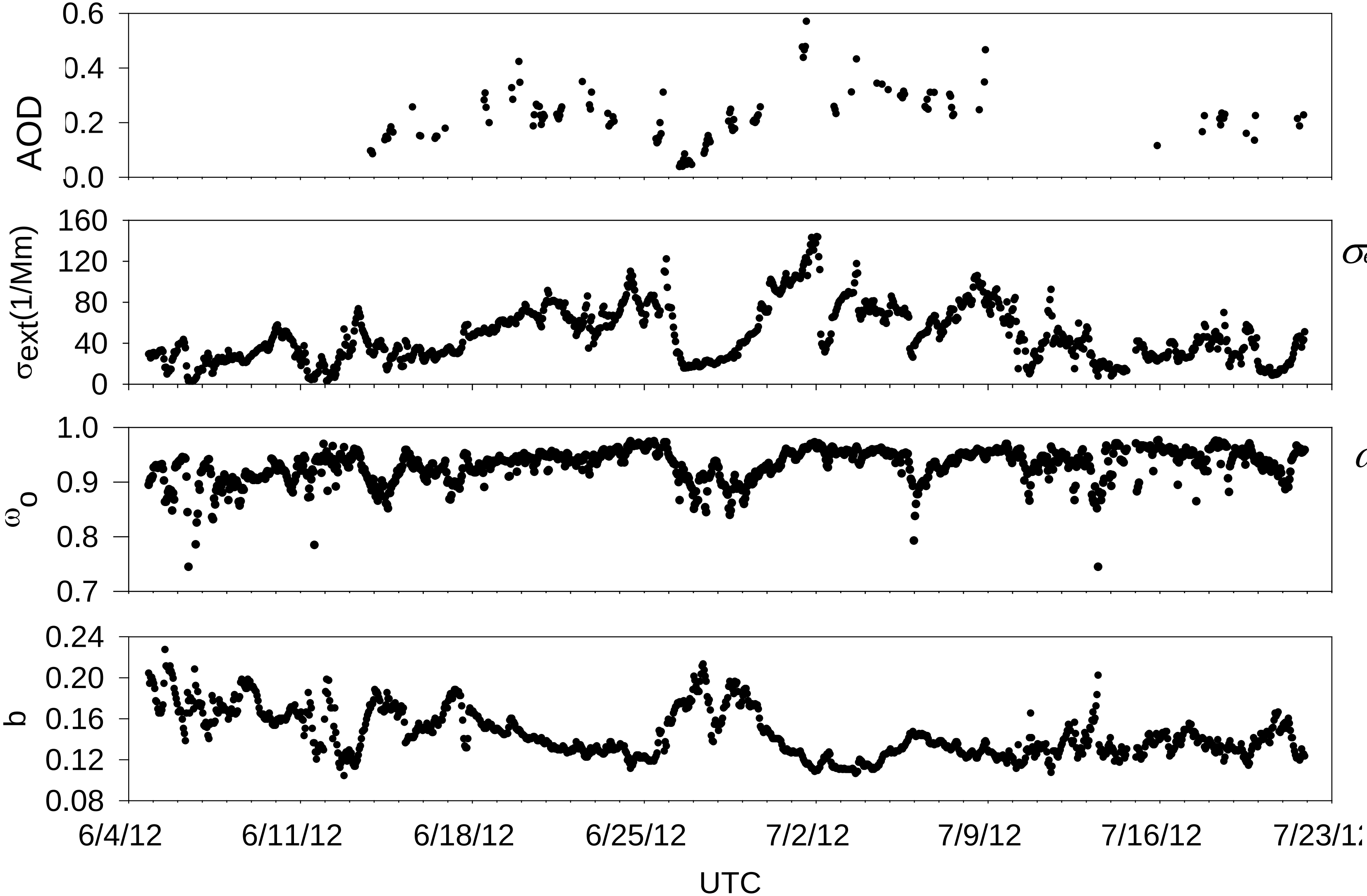
$$\omega_o = \frac{\sigma_{sp}}{\sigma_{sp} + \sigma_{ap}}$$

$$b = \frac{\sigma_{bsp}}{\sigma_{sp}}$$

$$a = -\frac{\log(\sigma_{sp}^{550} / \sigma_{sp}^{700})}{\log(550/700)}$$

$$R_{sp} = \frac{\sigma_{sp}(D_p < 1\mu m)}{\sigma_{sp}(D_p < 10\mu m)}$$

Aerosol optical depth (AOD) at 500 nm, and sub-10μm aerosol extinction (σ_{ext}), single scattering albedo ($\omega_\circ$), and back scattering fraction (*b*) at 550 nm

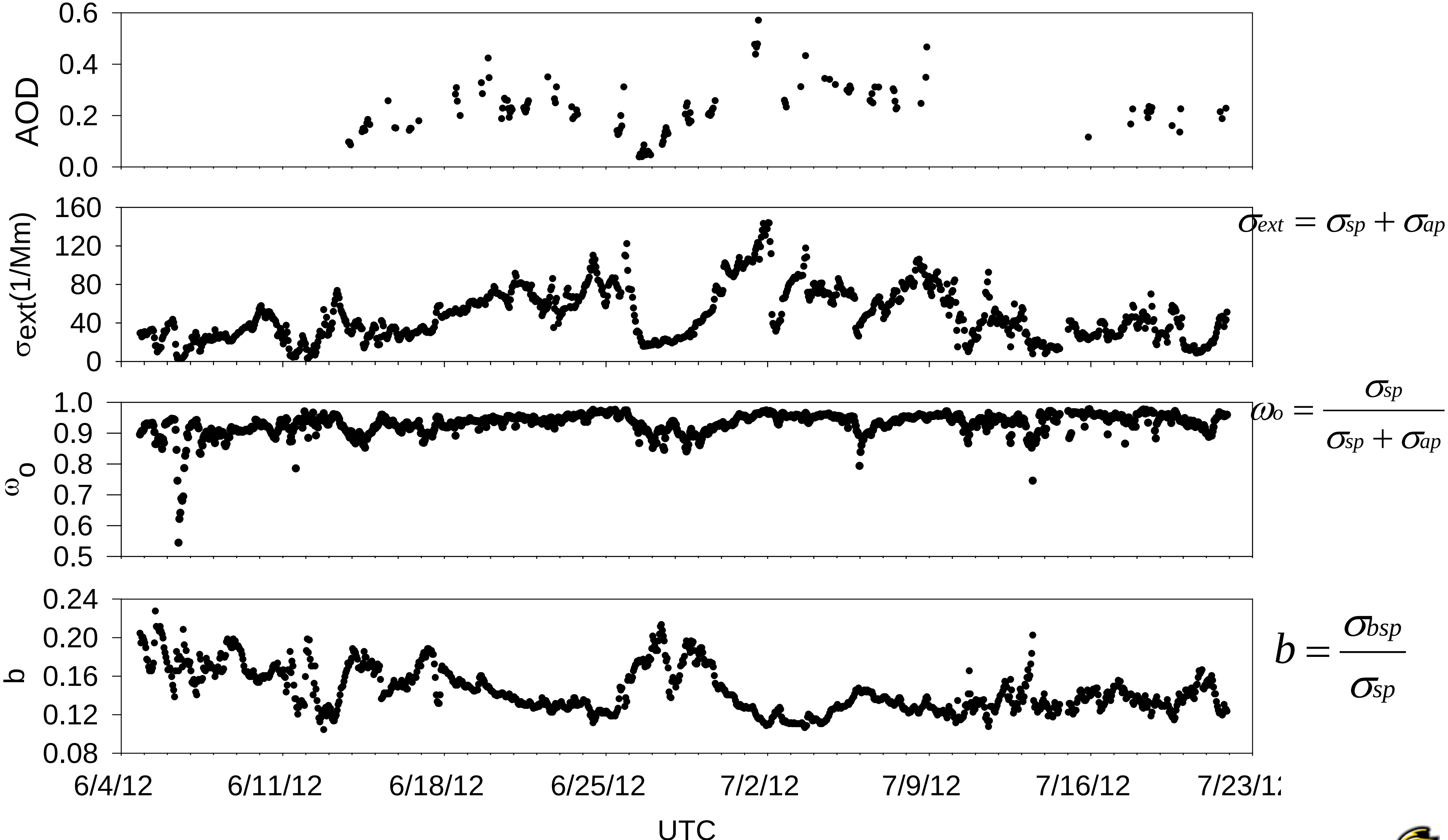


$$\sigma_{ext} = \sigma_{sp} + \sigma_{ap}$$

$$\omega_o = \frac{\sigma_{sp}}{\sigma_{sp} + \sigma_{ap}}$$

$$b = \frac{\sigma_{bsp}}{\sigma_{sp}}$$

Aerosol optical depth (AOD) at 500 nm, and sub-10μm aerosol extinction (σ_{ext}), single scattering albedo ($\omega_\circ$), and back scattering fraction (*b*) at 550 nm



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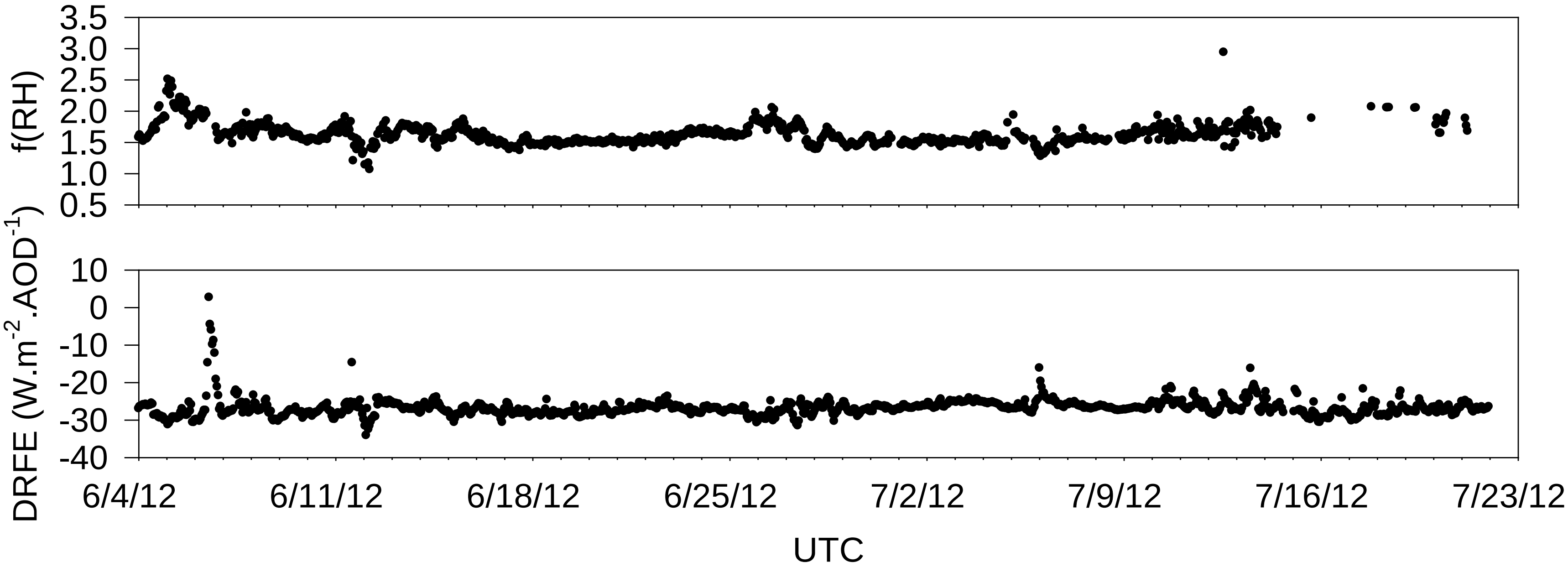


$$f(RH) = \frac{\sigma_{bsp}(85\%)}{\sigma_{sp}(40\%)}$$

Summer 2012 statistics of aerosol optical thickness (AOT) at 500 nm, and sub-10μm aerosol scattering (σ_{sp}), absorption (σ_{ap}), extinction (σ_{ext}), single-scattering albedo (ω), back-scatter fraction (*b*) at 550 nm, and Angstrom exponent (a)

	AOT_500	σ_{sp}	σ_{ap}	σ_{ext}
Mean	0.21	44.2	3.0	47.1
Stdev	0.10	25.3	1.3	26.2

	ω	*b*	a	R_{ap}	R_{sp}
Mean	0.927	0.146	0.598	0.90	0.94
Stdev	0.038	0.023	0.264	0.08	0.10

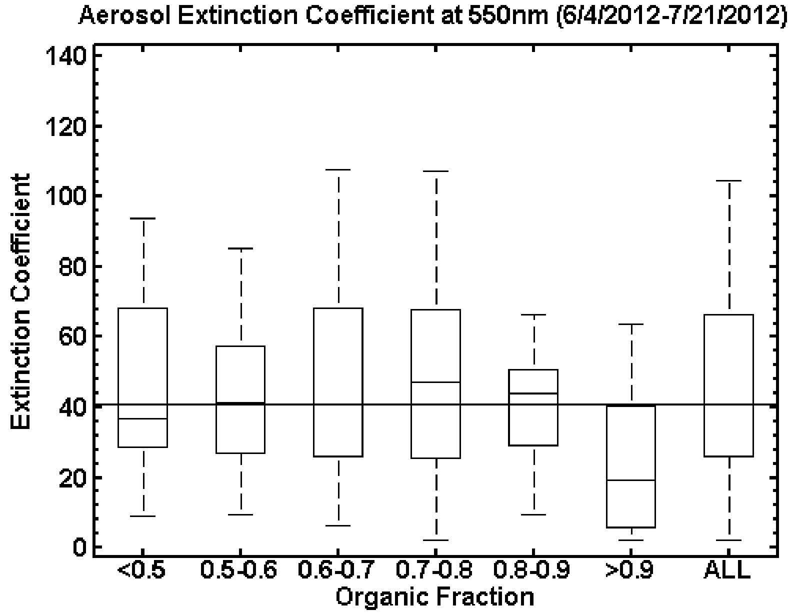
SGP 1996-2000

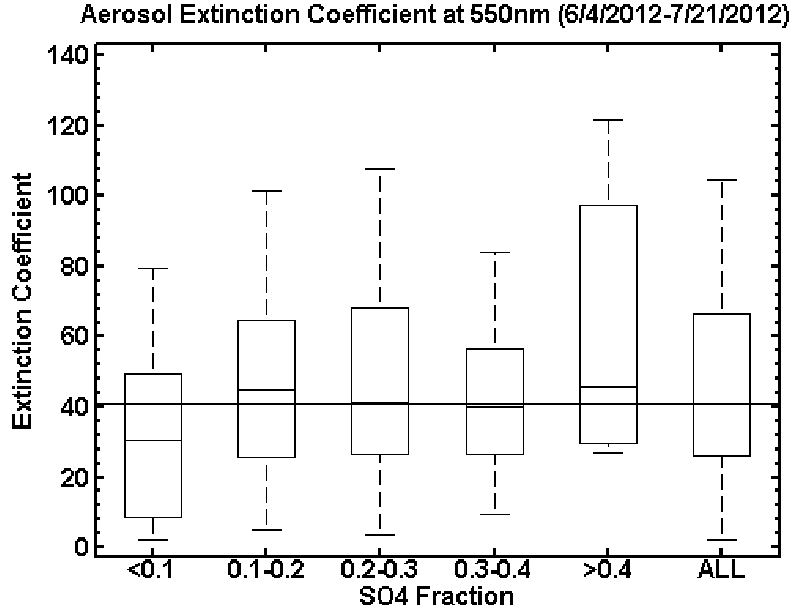
σ ap: 2.8 (June), 2.4 (July)

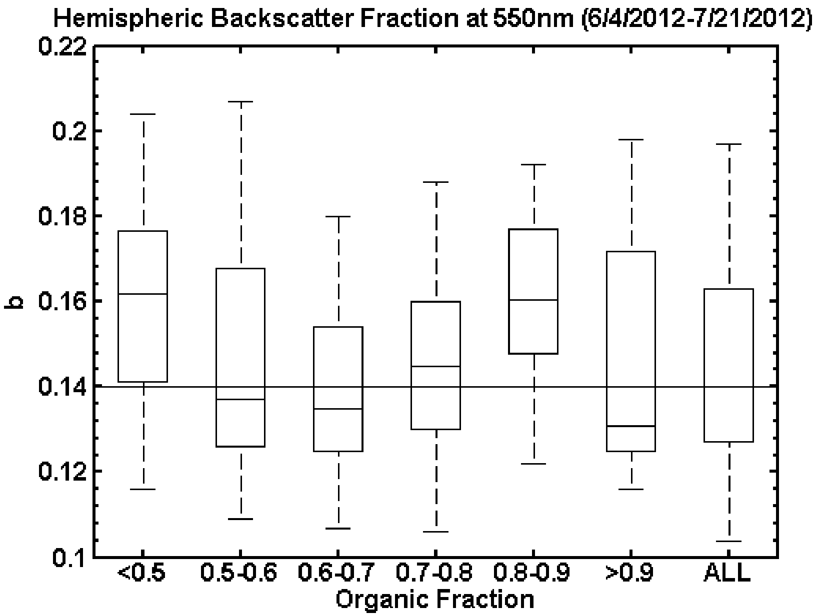
σ ap: 50 (June), 48 (July)

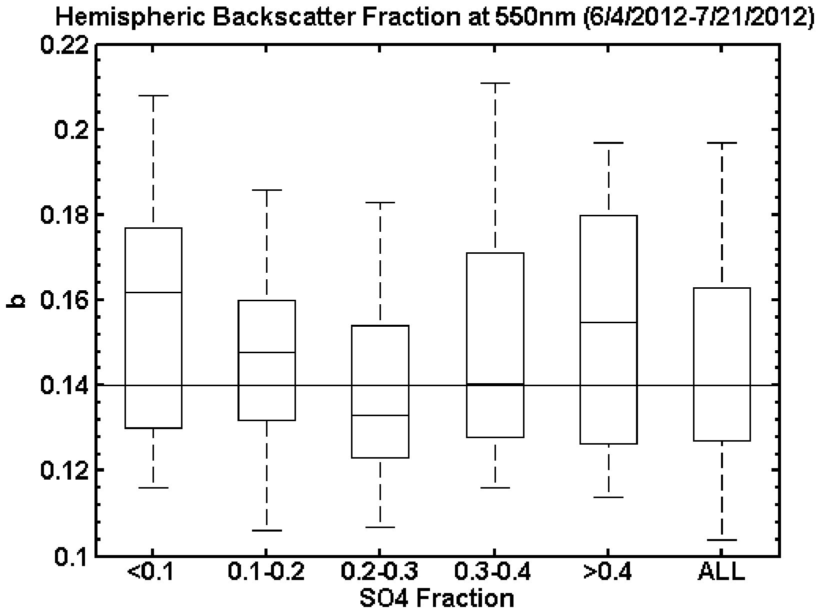
Ω: 0.92 (June), 0.95 (July)

Sheridan et al., 2001

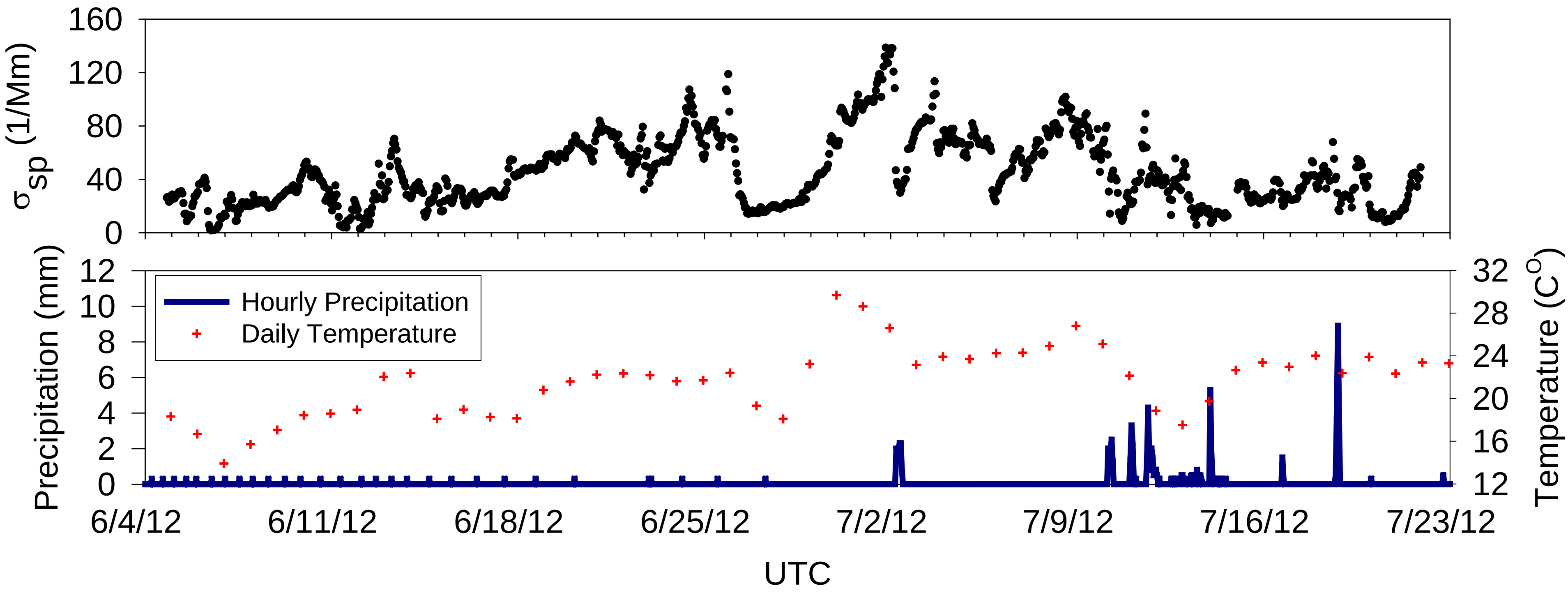

Aerosol Extinction Coefficient at 550nm (6/4/2012-7/21/2012)
Extinction Coefficient
0
20
40
60
80
100
120
140
<0.5
0.5-0.6
0.6-0.7
0.7-0.8
0.8-0.9
>0.9
ALL
Organic Fraction

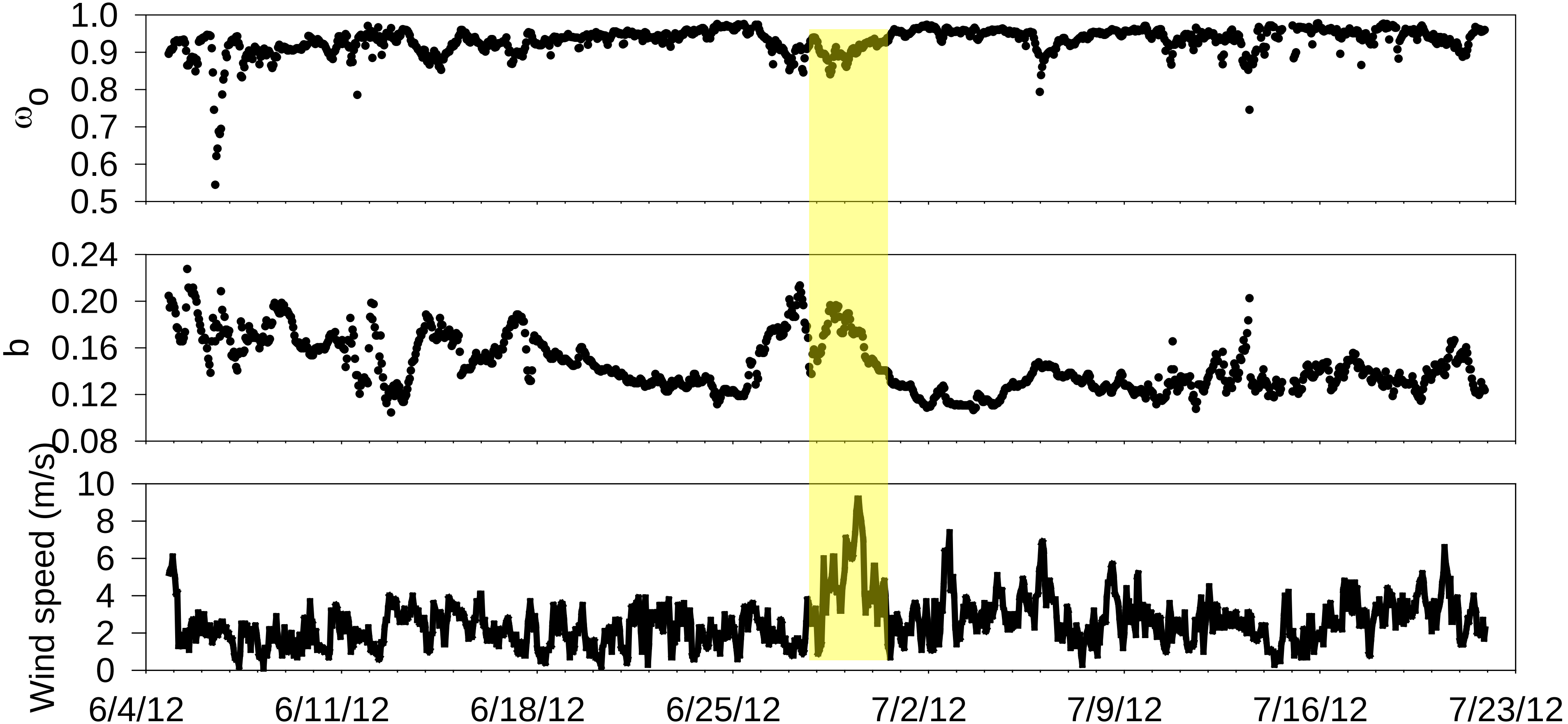

Aerosol Extinction Coefficient at 550nm (6/4/2012-7/21/2012)
Extinction Coefficient
0
20
40
60
80
100
120
140
<0.1
0.1-0.2
0.2-0.3
0.3-0.4
>0.4
ALL
SO4 Fraction


Hemispheric Backscatter Fraction at 550nm (6/4/2012-7/21/2012)
b
0.1
0.12
0.14
0.16
0.18
0.2
0.22
<0.5
0.5-0.6
0.6-0.7
0.7-0.8
0.8-0.9
>0.9
ALL
Organic Fraction


Hemispheric Backscatter Fraction at 550nm (6/4/2012-7/21/2012)
b
0.1
0.12
0.14
0.16
0.18
0.2
0.22
<0.1
0.1-0.2
0.2-0.3
0.3-0.4
>0.4
ALL
SO4 Fraction

Meteorological relationships





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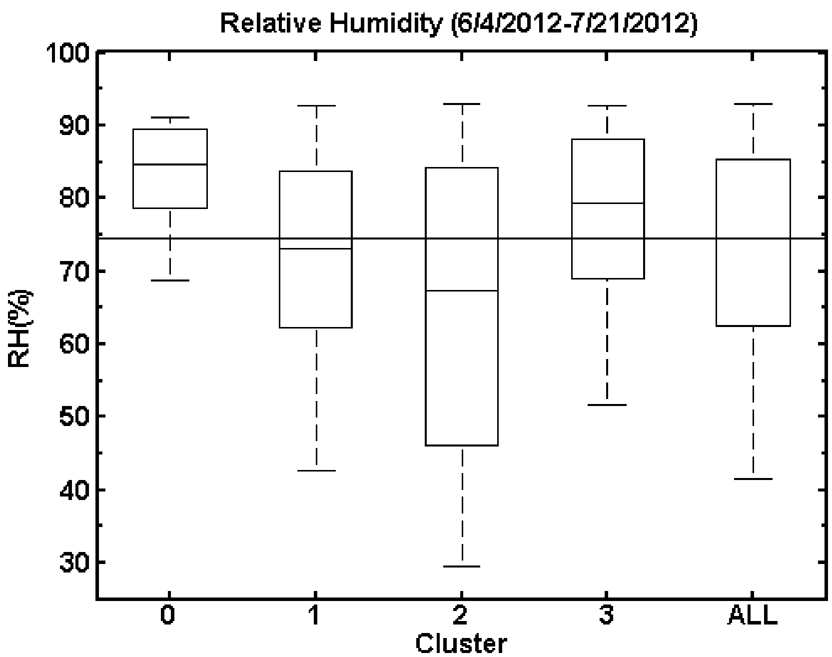
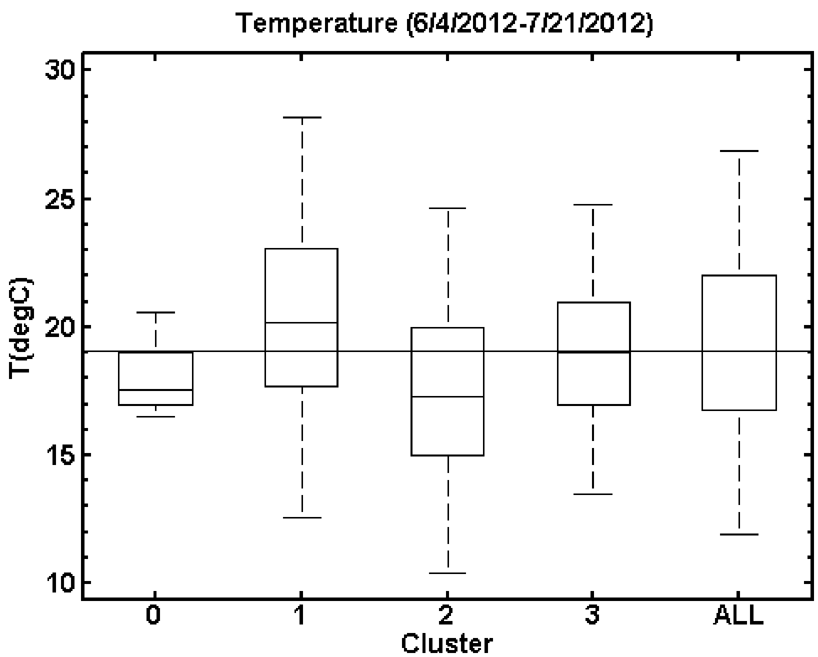
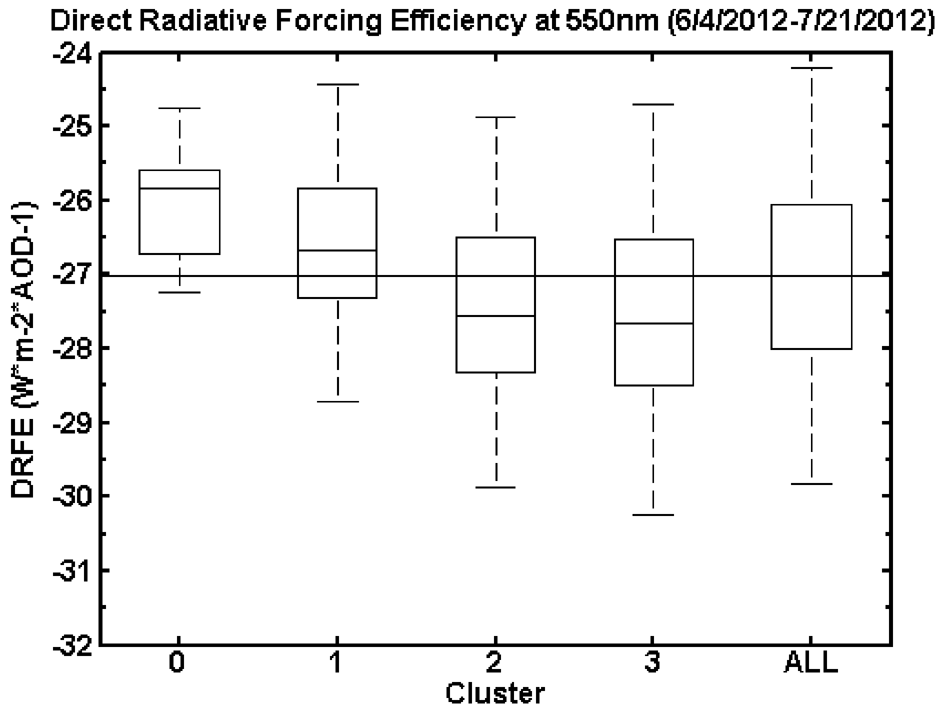
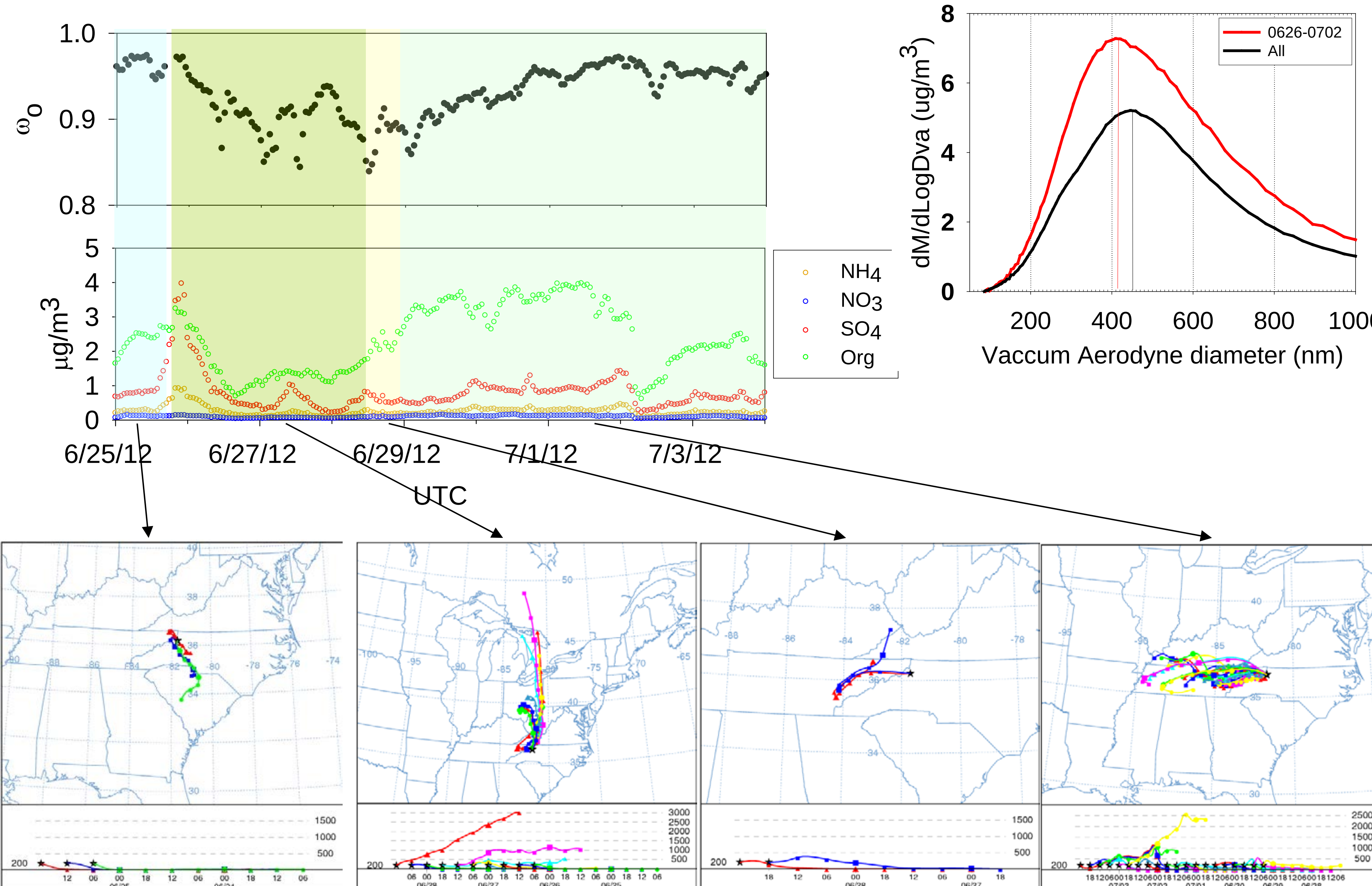

Relative Humidity (6/4/2012-7/21/2012)
RH(%)
100
90
80
70
60
50
40
30
0
1
2
3
ALL
Cluster


Temperature (6/4/2012-7/21/2012)
T(degC)
30
25
20
15
10
0
1
2
3
ALL
Cluster

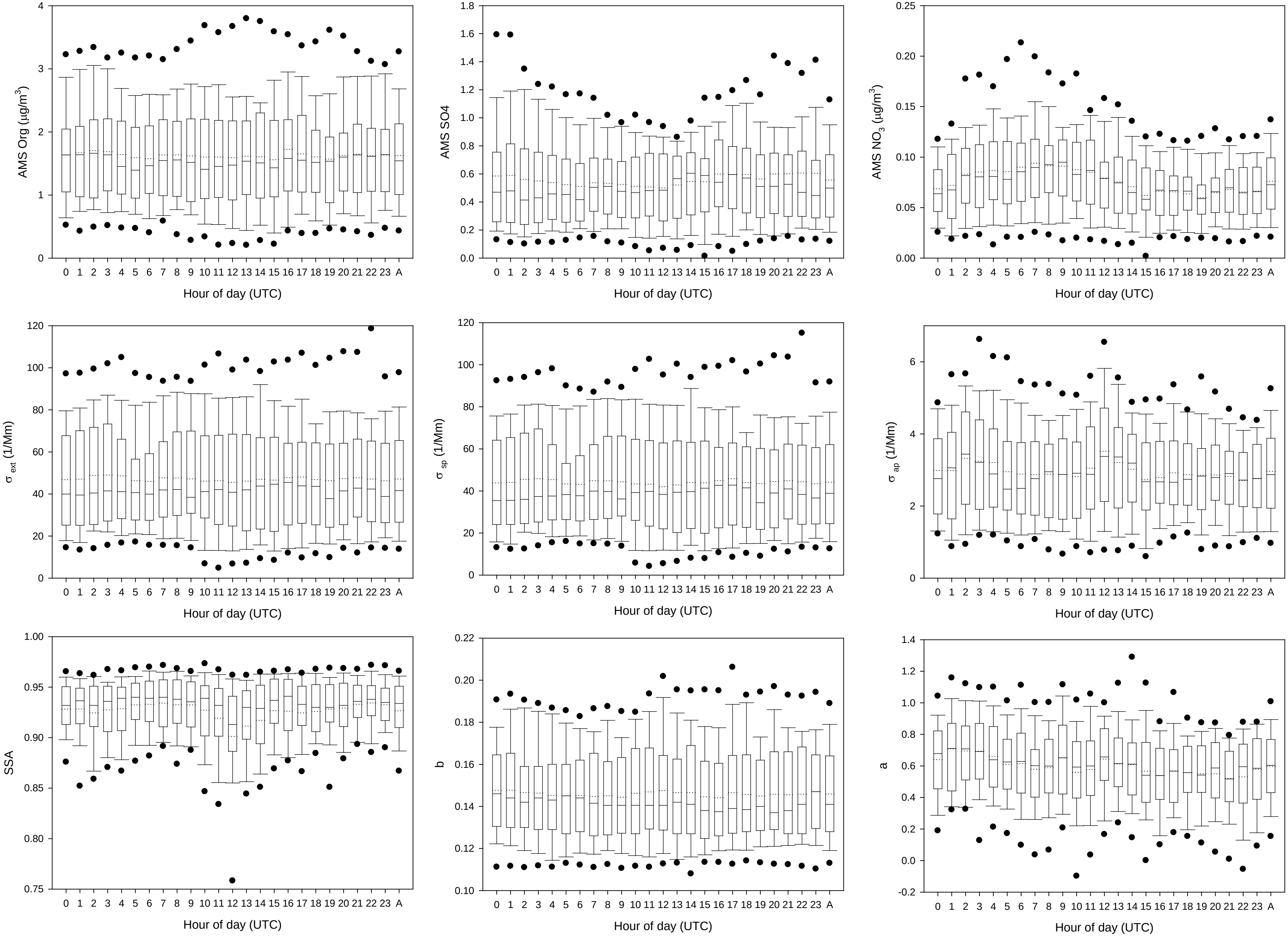


Direct Radiative Forcing Efficiency at 550nm (6/4/2012-7/21/2012)
DRFE (W*m-2*AOD-1)
-24
-25
-26
-27
-28
-29
-30
-31
-32
0
1
2
3
ALL
Cluster

Case study

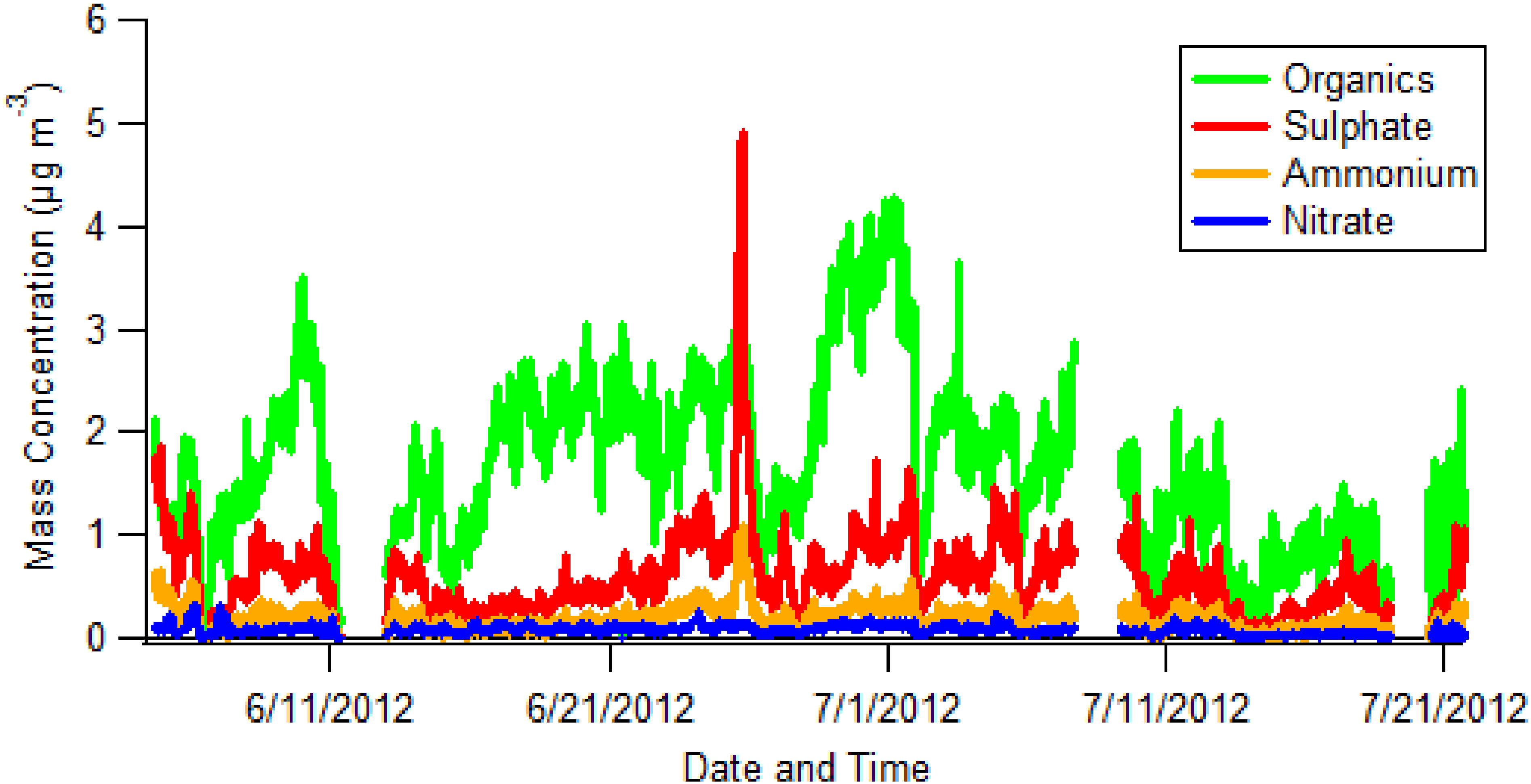


1.0
0.9
0.8
ω_0
5
4
3
2
1
0
$\mu g/m^3$
NH_4
NO_3
SO_4
Org
6/25/12
6/27/12
6/29/12
7/1/12
7/3/12
UTC
8
6
4
2
0
dM/dLogDva (ug/m^3)
0626-0702
All
200
400
600
800
1000
Vaccum Aerodyne diameter (nm)

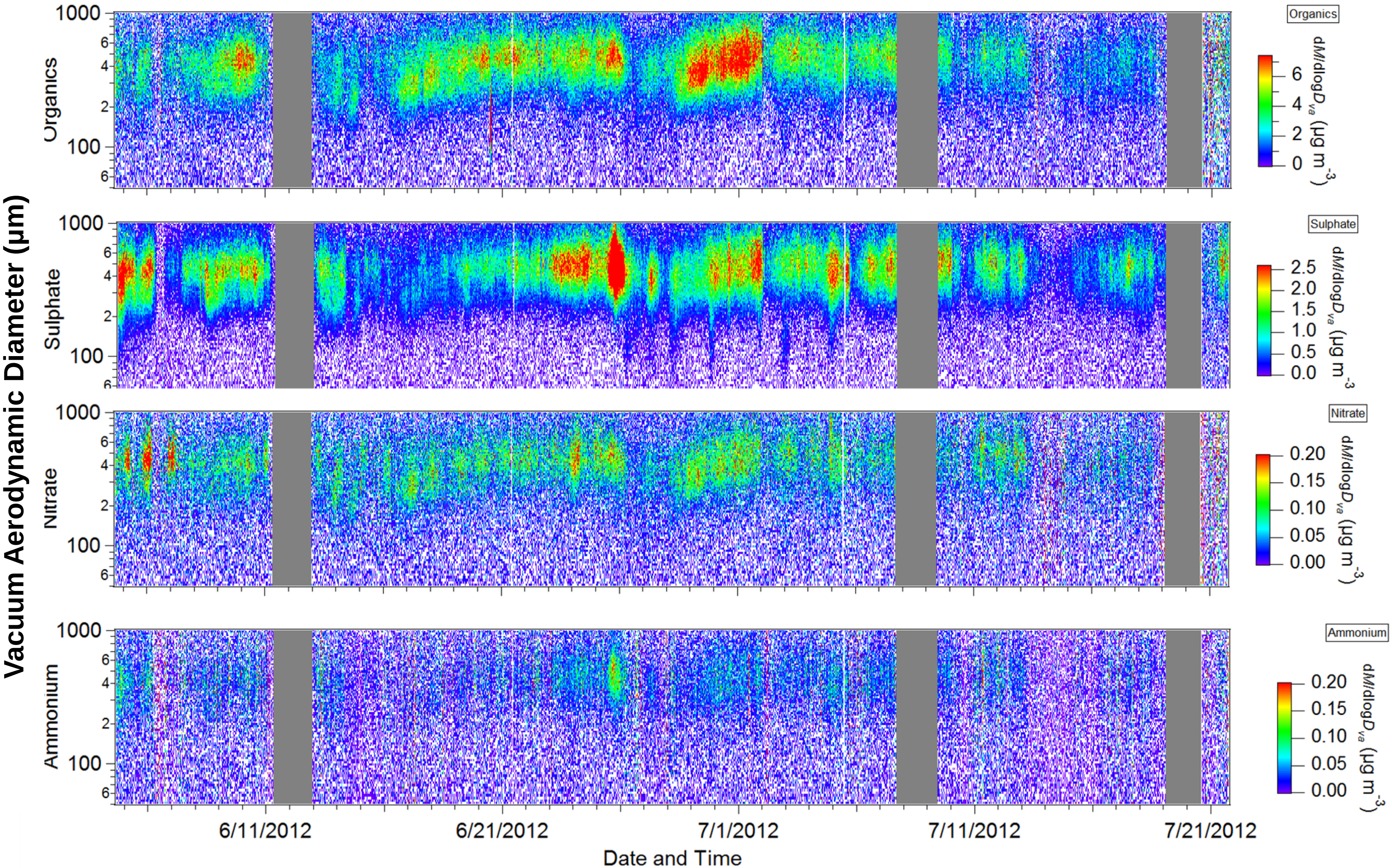

AMS Org (µg/m3)
AMS SO4
AMS NO3 (µg/m3)
σ ext (1/Mm)
σ sp (1/Mm)
σ ap (1/Mm)
SSA
b
a
Hour of day (UTC)

Time series in Summer 2012

Chemical composition

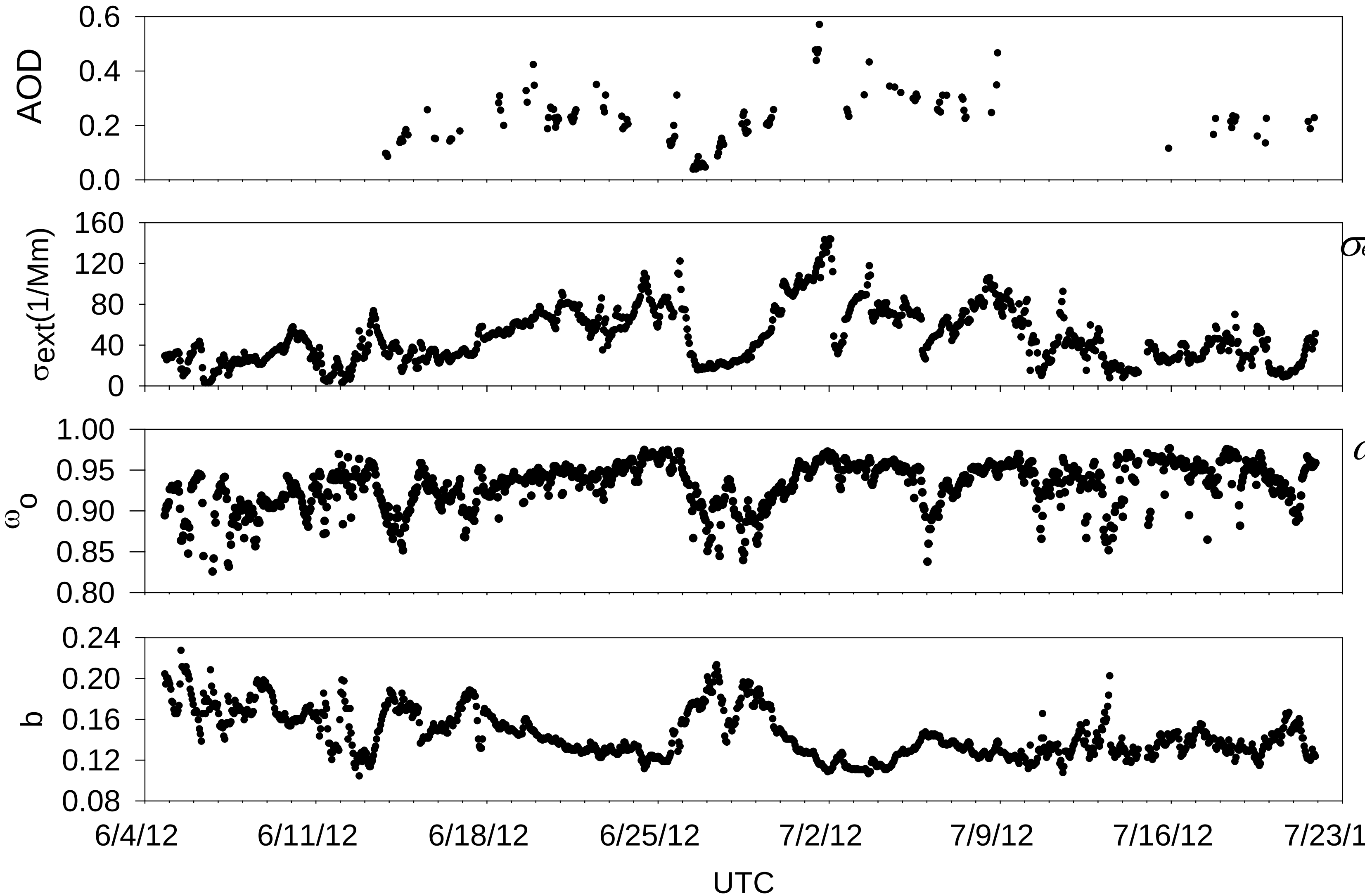


Size distribution



Appalachian STATE UNIVERSITY.

Aerosol optical depth (AOD) at 500 nm, and sub-10μm aerosol extinction (σ_{ext}), single scattering albedo (ω_o), and back scattering fraction (b) at 550 nm

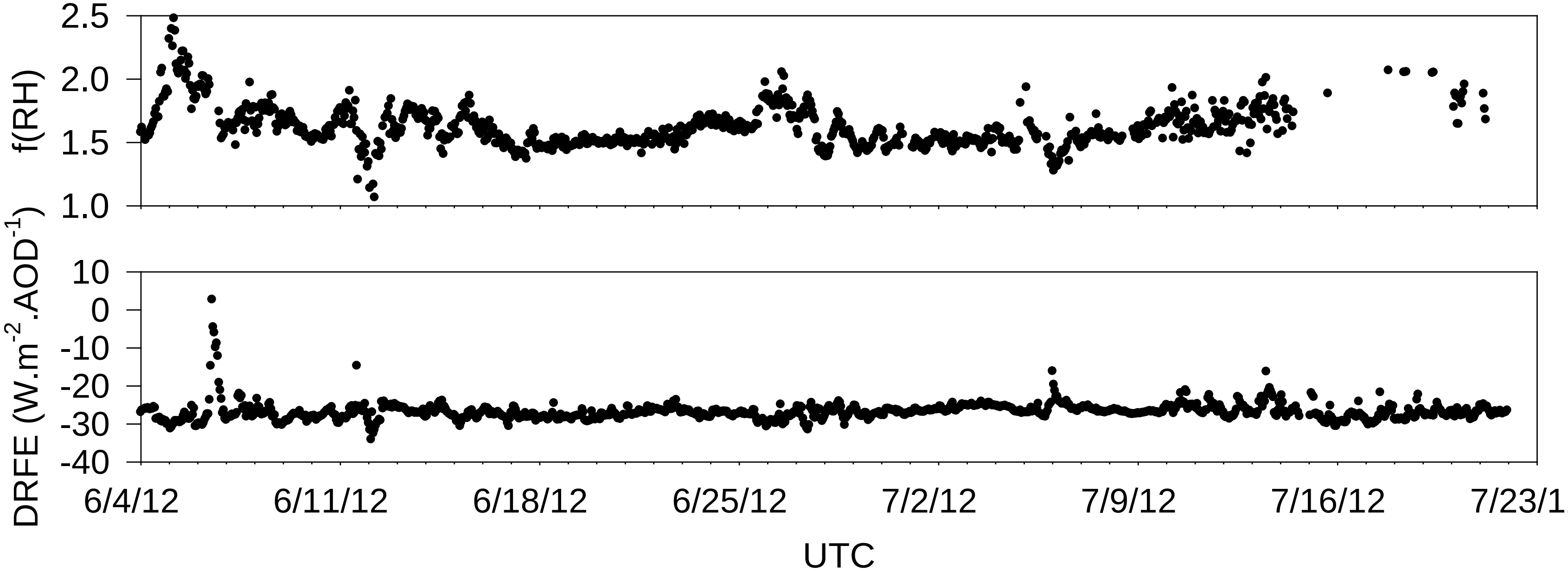


$$\sigma_{ext} = \sigma_{sp} + \sigma_{ap}$$

$$\omega_o = \frac{\sigma_{sp}}{\sigma_{sp} + \sigma_{ap}}$$

$$b = \frac{\sigma_{bsp}}{\sigma_{sp}}$$

Aerosol hygroscopic growth factor (f(RH)) and directive radiative forcing efficiency (DRFE)



$$f(RH) = \frac{\sigma_{sp}(85\%)}{\sigma_{sp}(40\%)}$$