Studying the Relationship Between Column and Vertically Resolved Aerosol Measurements To Better Estimate Uncertainty and Bias in Deriving Surface PM with Satellite Observations

Allen Chu
GEST
UMBC/GSFC

DISCOVER-AQ STM
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Jay Al-Saadi (NASA LaRC)

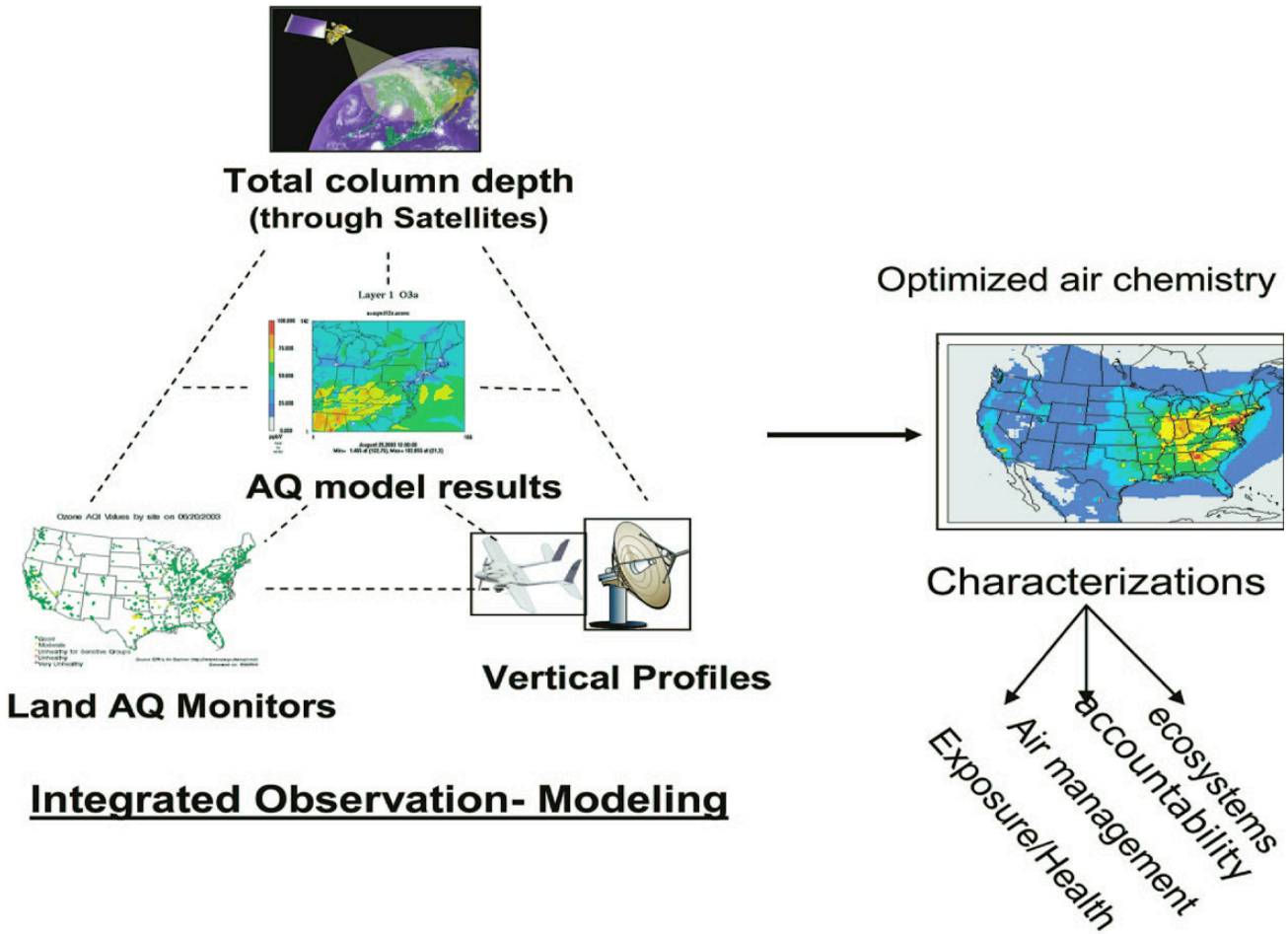
&

HSRL Team

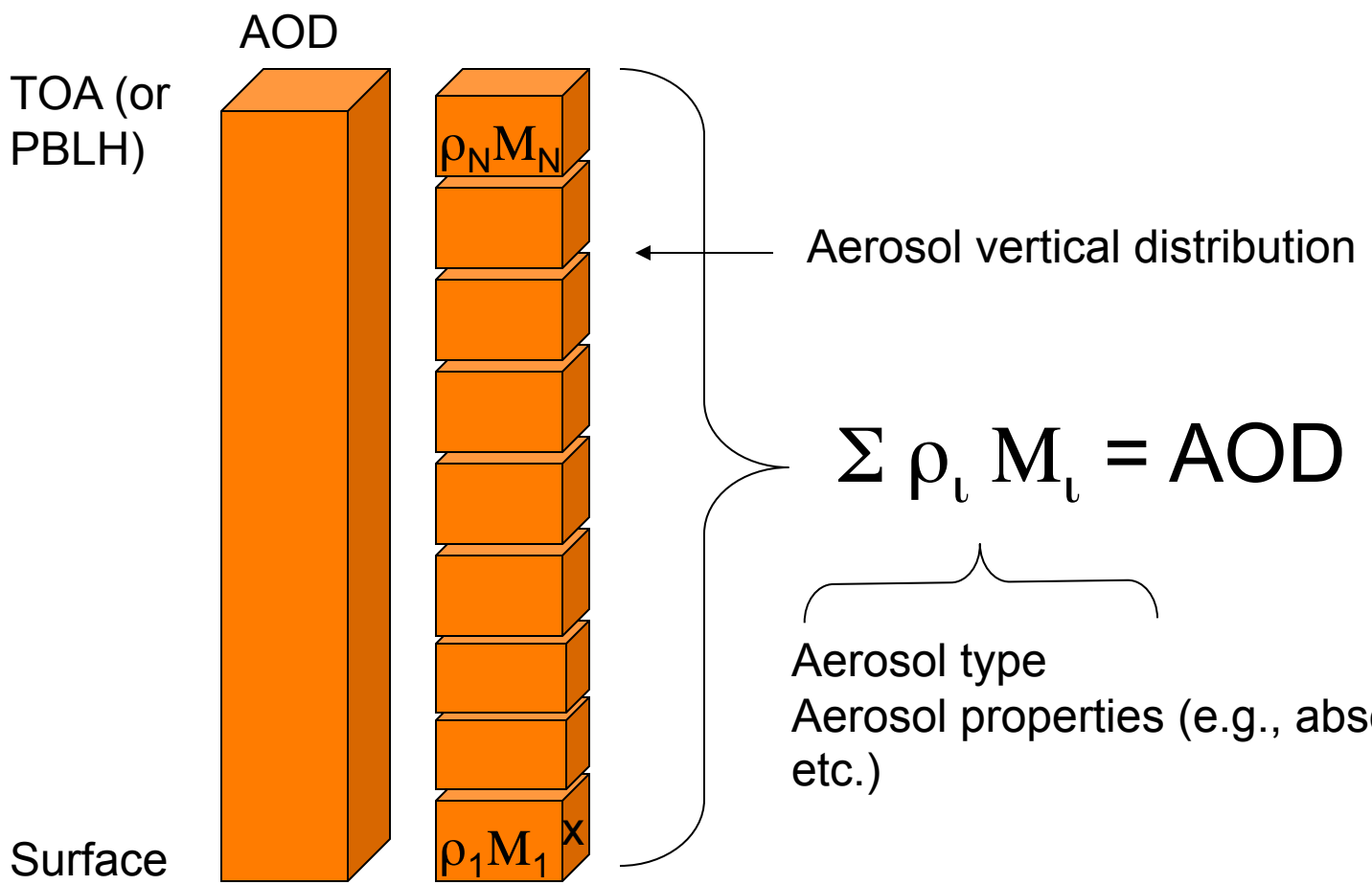
Chris Hostetler (NASA LaRC)
Richard Ferrare (NASA LaRC)
Sharon Burton (NASA LaRC)

Column Measurements: AERONET, HSRL, satellite AOD retrieval
Vertical Measurements: MPLNet, HSRL, CALIPSO

Uncertainty: satellite AOD retrievals (aerosol properties: absorption, size, shape, etc.)
Bias: comparison of satellite AOD against ground truths (AERONET, HSRL, MPLNet) with PM mass concentration



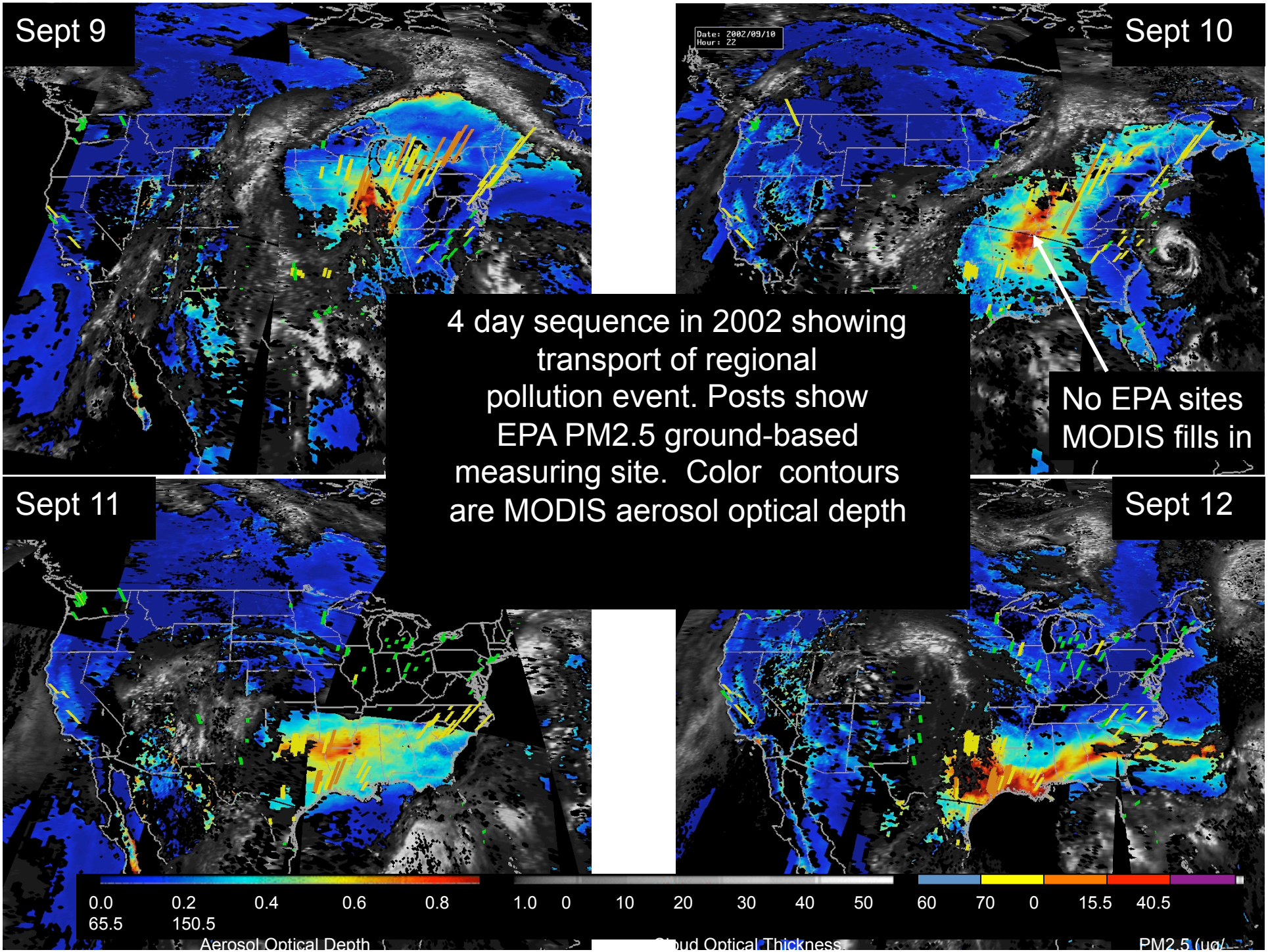
Relationship between Aerosol Optical Depth and Particulate Matter Mass Concentration Observed at Surface



$$\underbrace{\Sigma\, \rho_\iota\, M_\iota}_{\text{Aerosol type, Aerosol properties (e.g., absorption, hydration, etc.)}} = \text{AOD}$$

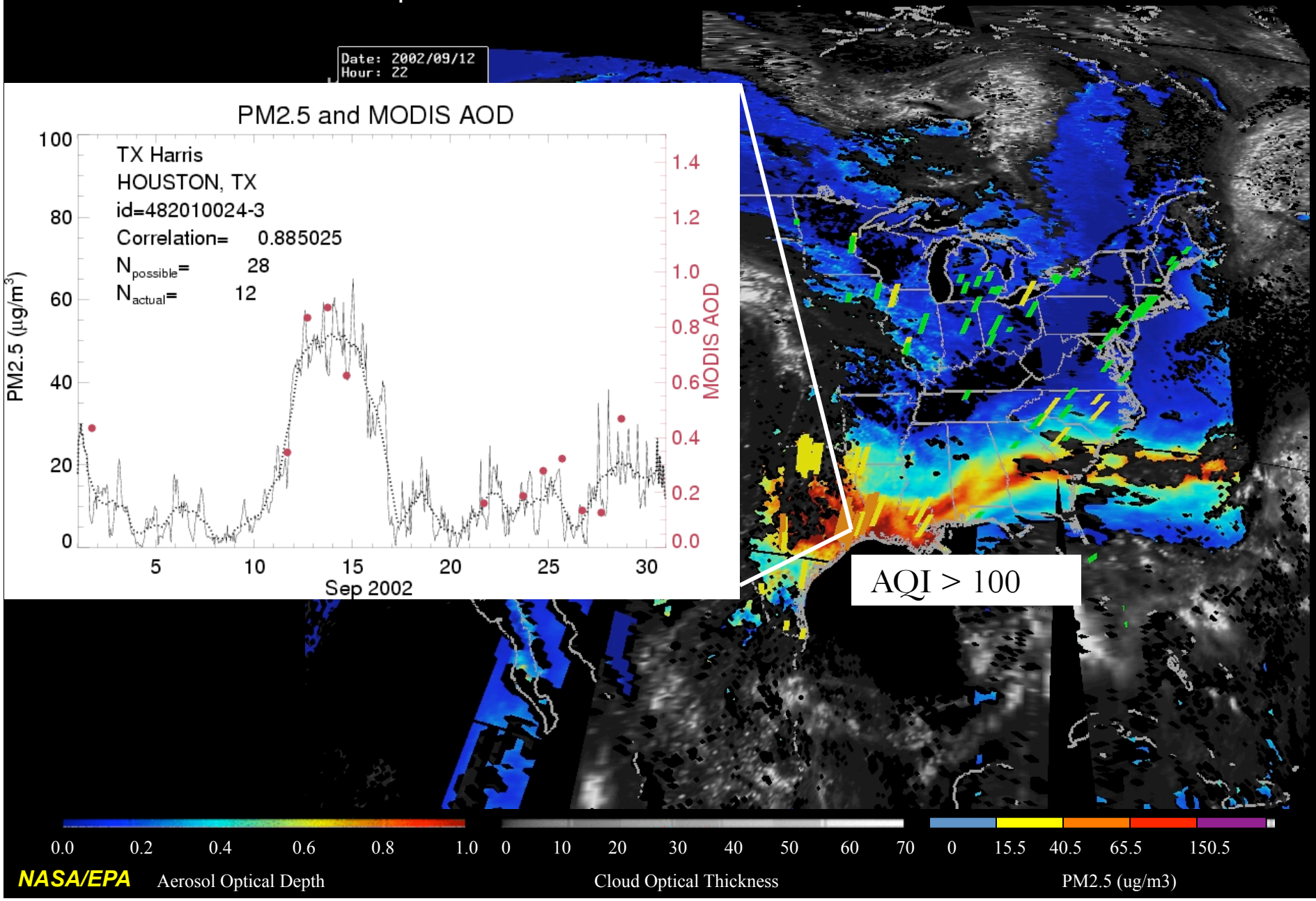
Limited MPLNet sites and Measurements in US

CART site: 2003
GSFC: 2001-2010
Monterey: 2003-2004, 2007-2009
Thompson Farm: 2007-2010
Trinidad Head: 2005-2010
UMBC: 2010

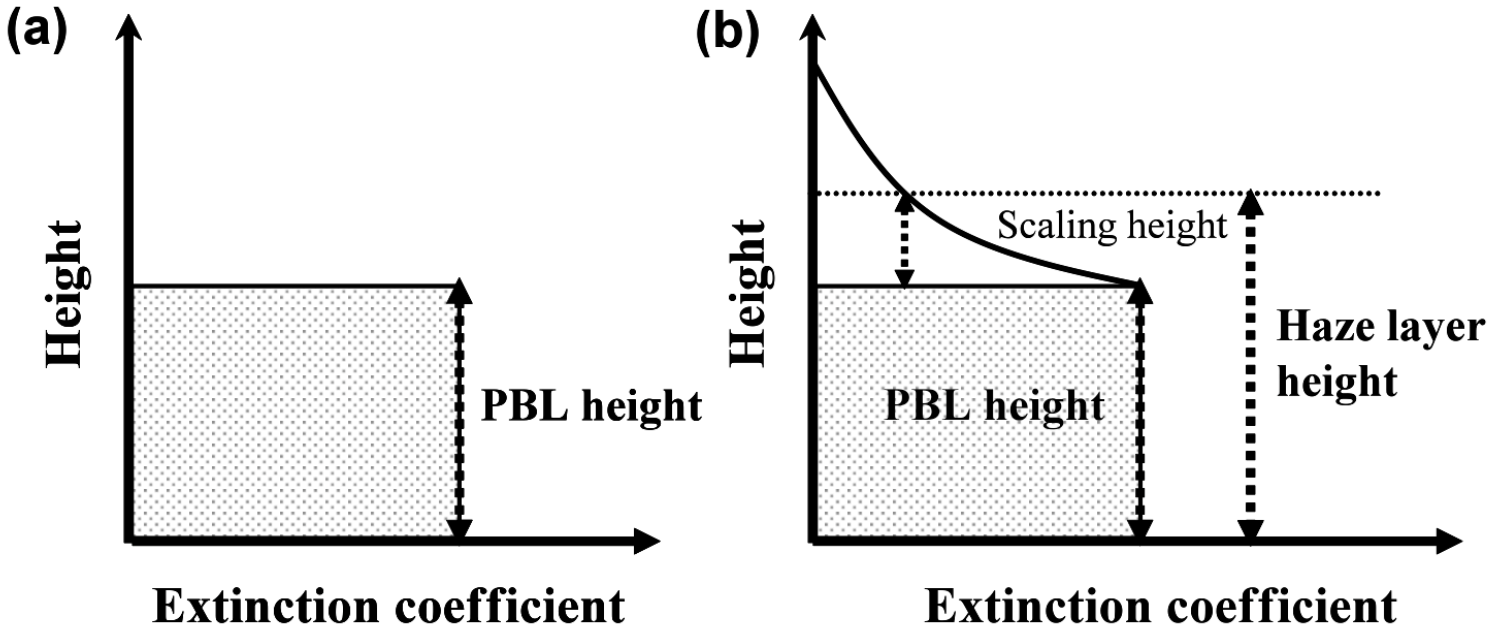


4 day sequence in 2002 showing transport of regional pollution event. Posts show EPA PM2.5 ground-based measuring site. Color contours are MODIS aerosol optical depth

12 Sept. 2002-The high AOD from MODIS is seen stretching along the entire Gulf Coast and extending out into the Atlantic Ocean. This transport was caused by T.S. Gustav pulling off into the North Atlantic and the development of T.S. Hanna in the Gulf.



NASA/EPA



$$\int_0^\infty \sigma_{PBLH}\, e^{-\frac{z}{H}}\, dz = \sigma_{PBLH}\, H \approx \sigma_S\, H$$

$AOD = \sigma_s\ PBLH$

$\sigma_s = AOD / PBLH$

σ_s: Surface Extinction (1/km)

$AOD = \sigma_s\,(PBLH + H)$

$\sigma_s = AOD / (PBLH + H)$

$= AOD / HLH$

Linear Approximation of AOD with Aerosol Mixing Height and Surface PM

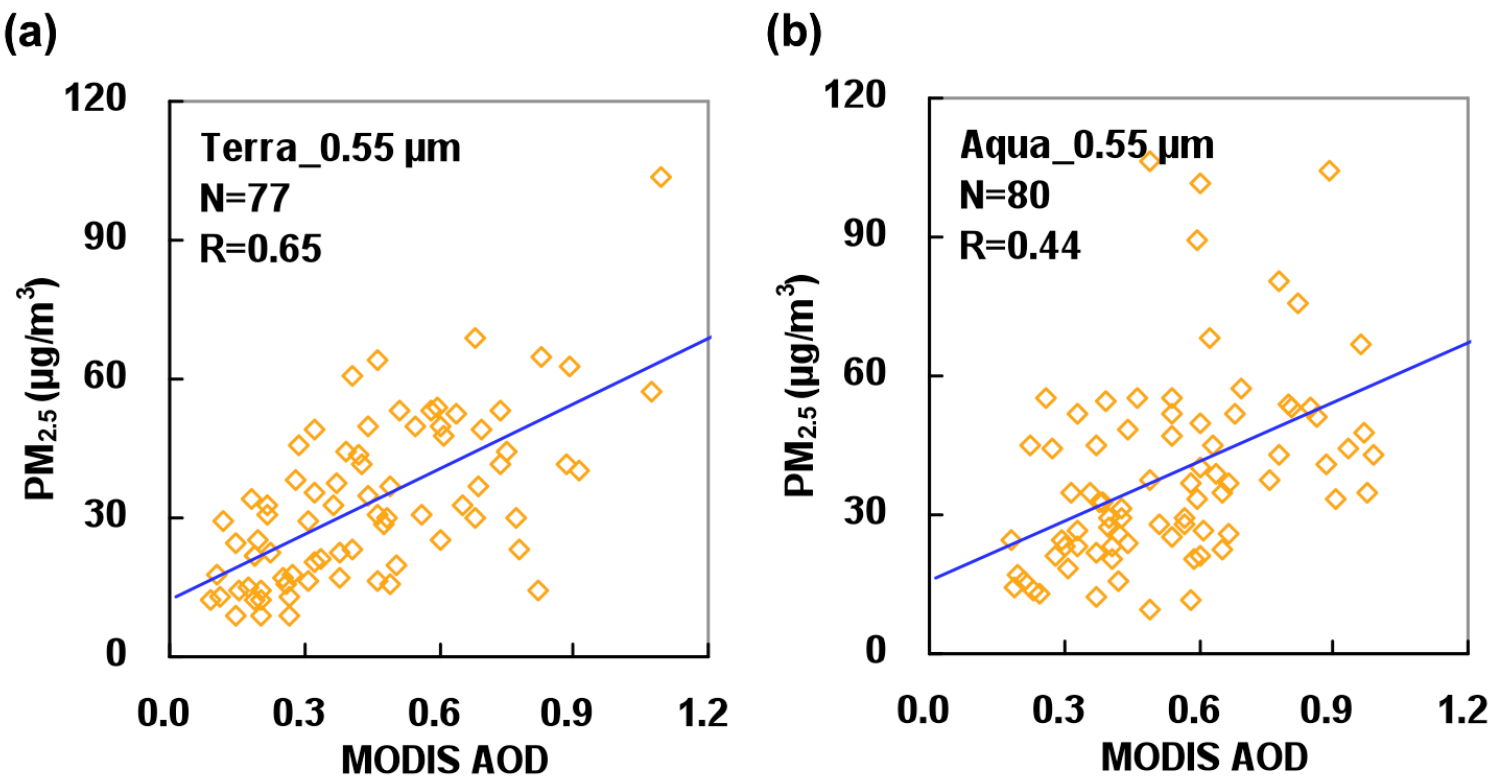
$$PM \approx \frac{\tau_{a,\,0.55\mu m}}{[\,f(RH)\sigma^{ext}_{dry,0.55\mu m}\,]_{surface}\,L_{mix}}$$

Aerosol Mixing Height: PBLH or HLH

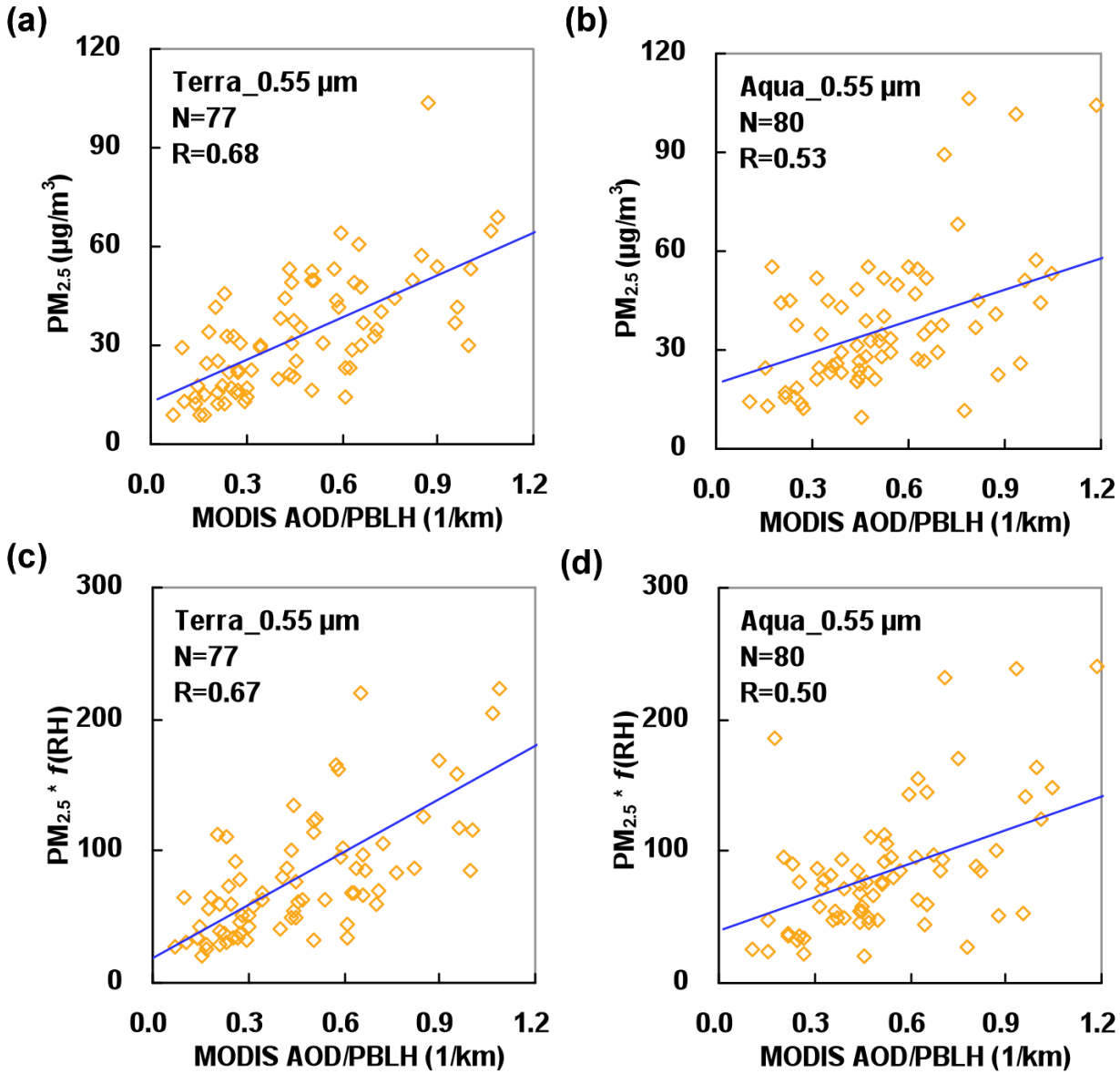
Taiwan Study (2006-2009)

MPLNet, AERONET, PM2.5 Measurements
MPLNet and AERONET are collocated at NCU
PM2.5 is 2 km away from NCU

Linear Regressions of $PM_{2.5}$ and AOD_{MODIS}



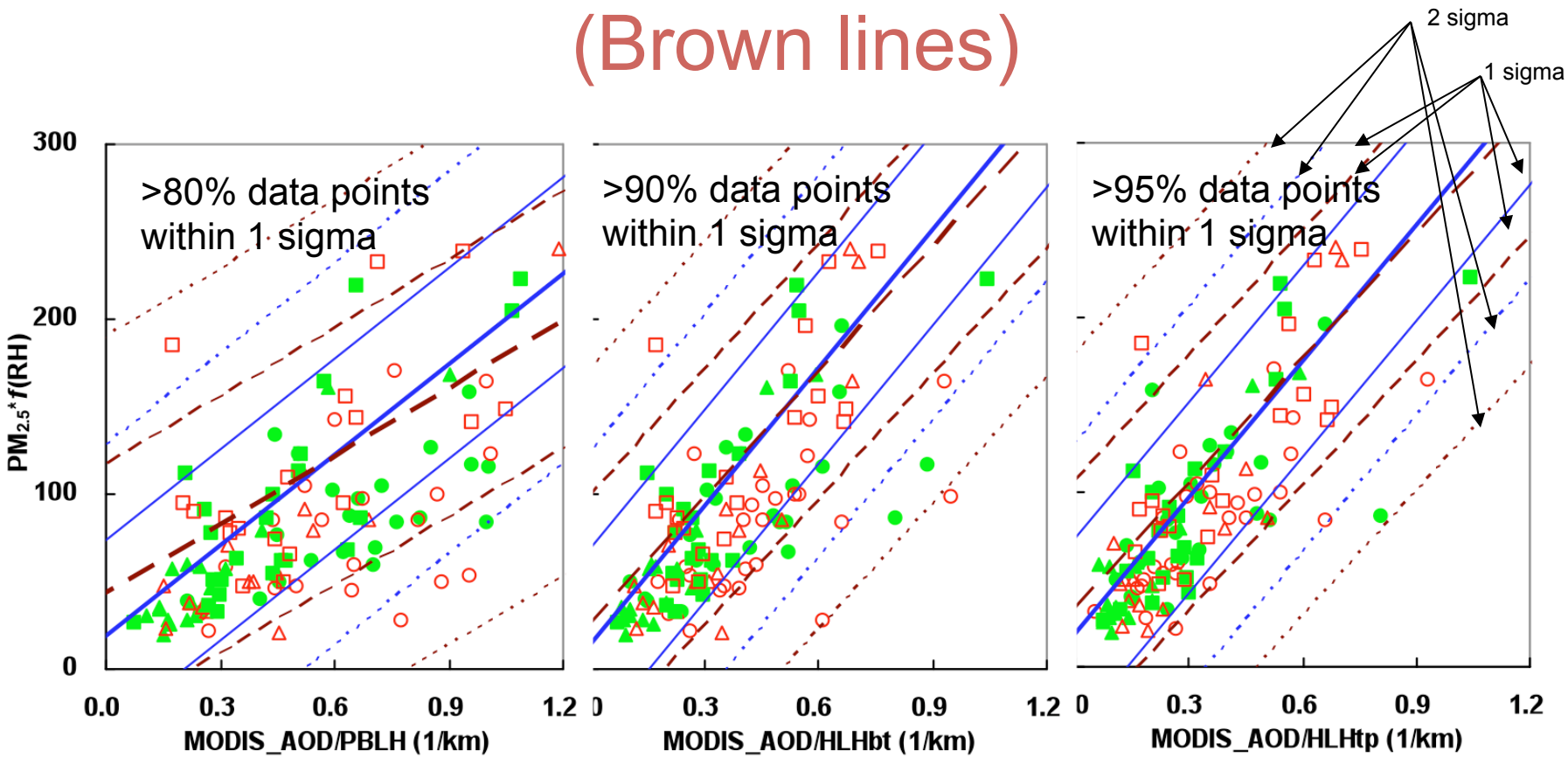
Linear Regressions of $PM_{2.5}$ and AOD_{MODIS}/PBLH(upper) & $PM_{2.5}$•*f*(RH) and AOD_{MODIS}/PBLH(lower)



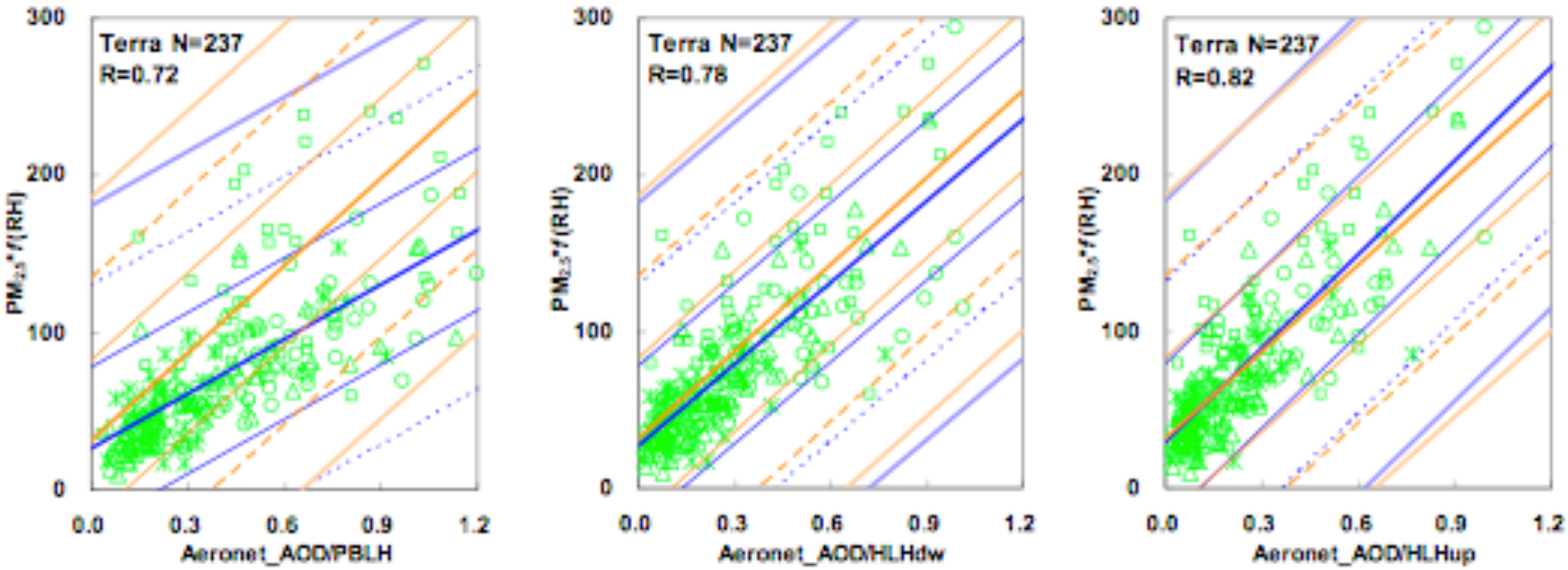
RH between 60% - 70%;

No AOD retrieval for RH > 70%

Results of $PM_{2.5}$•*f*(RH) and AOD_{MODIS}/Heights (Blue lines) Overlaid on Linear Regressions of $PM_{2.5}$•*f*(RH) and $AOD_{AERONET}$/Heights (Brown lines)



Linear Regression Results (Blue) of $PM_{2.5}$•*f*(RH) and MPL Near Surface Extinction (data) Overlaid on $PM_{2.5}$•*f*(RH) vs. $AOD_{AERONET}$/HLH (Gold) and Data



Remarks of Taiwan Study:

1) Relationship between $AOD_{AERONET}$ and PM2.5 shows a strong seasonality
(R_{spring}= 0.4-0.5: R_{summer}= 0.6-0.7; R_{autumn}=0.7-0.8; R_{winter} =0.5-0.6)

2) PBL height plays an important role in correlating $AOD_{AERONET}$ with PM2.5 (R_{spring}=0.6-0.7: R_{summer}=0.6-0.7; R_{autumn}=0.8-0.9; R_{winter} =0.7)

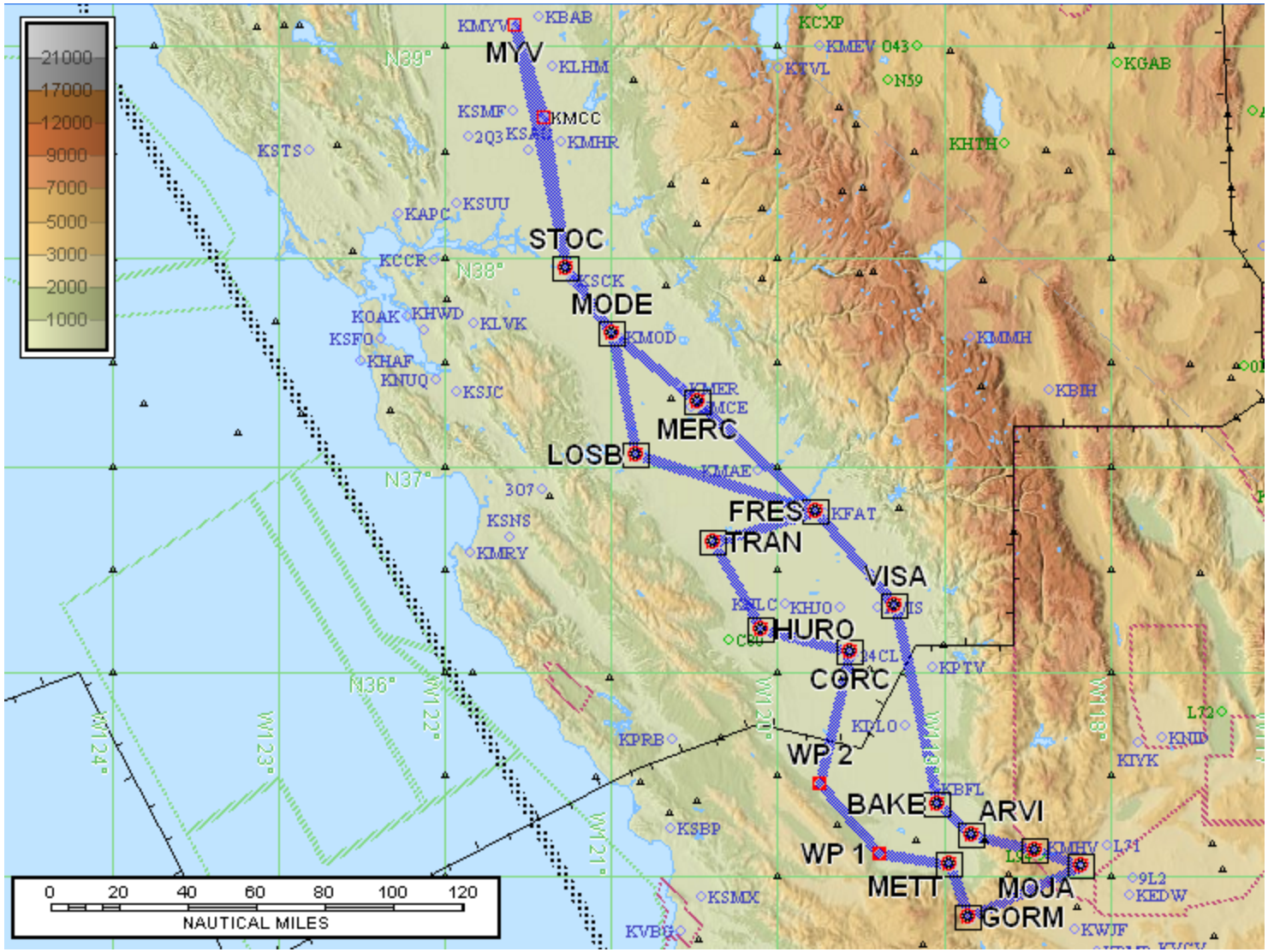
3) Haze layer height improves the correlation in the presence of elevated aerosol layers
(R_{spring}=0.7-0.8: R_{summer}=0.6-0.7; R_{autumn}≥ 0.9; R_{winter} = 0.8-0.85)

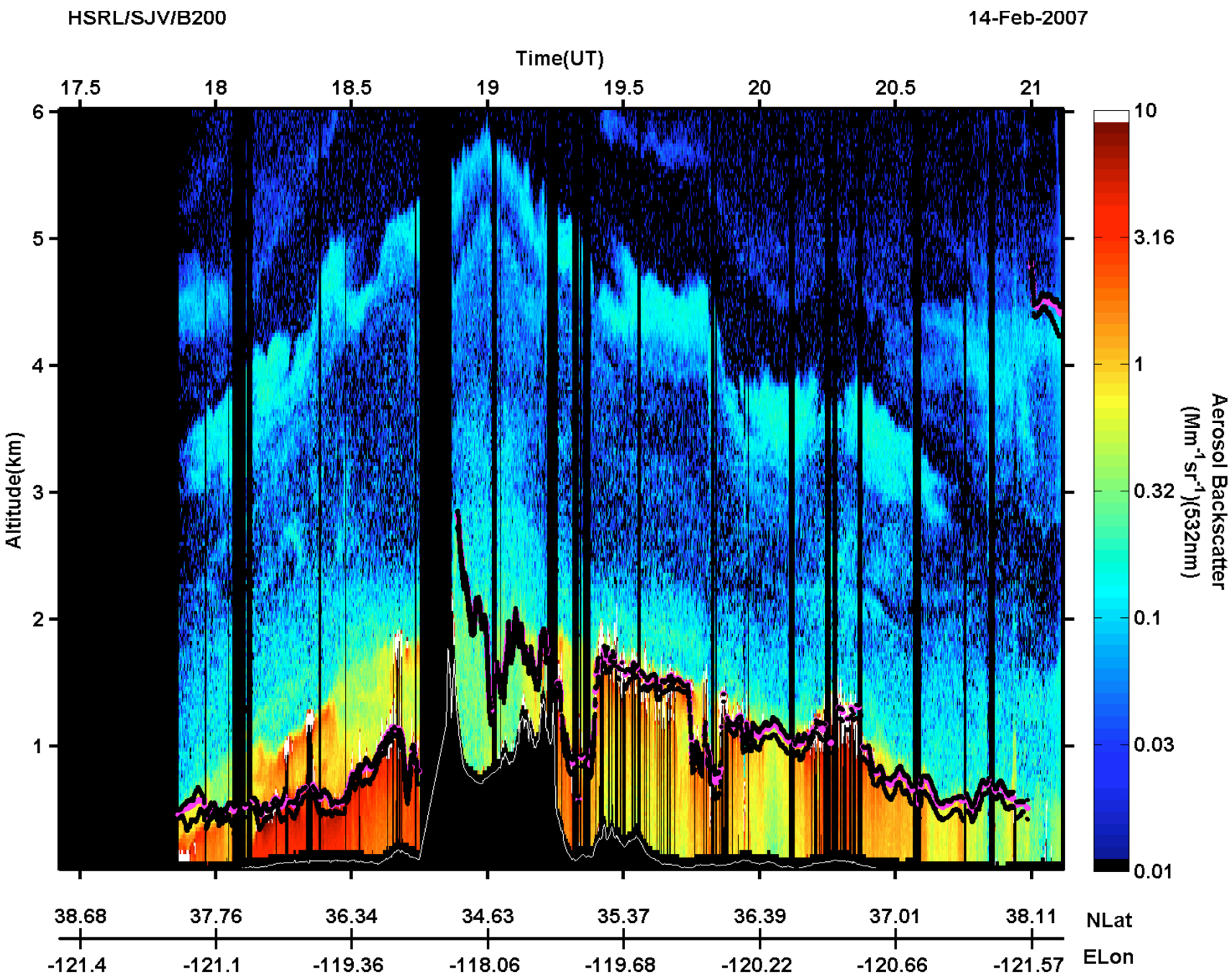
4) AOD_{MODIS} products uphold the relationship derived from AERNET except summer season (95% data within 1 sigma of linear regression)

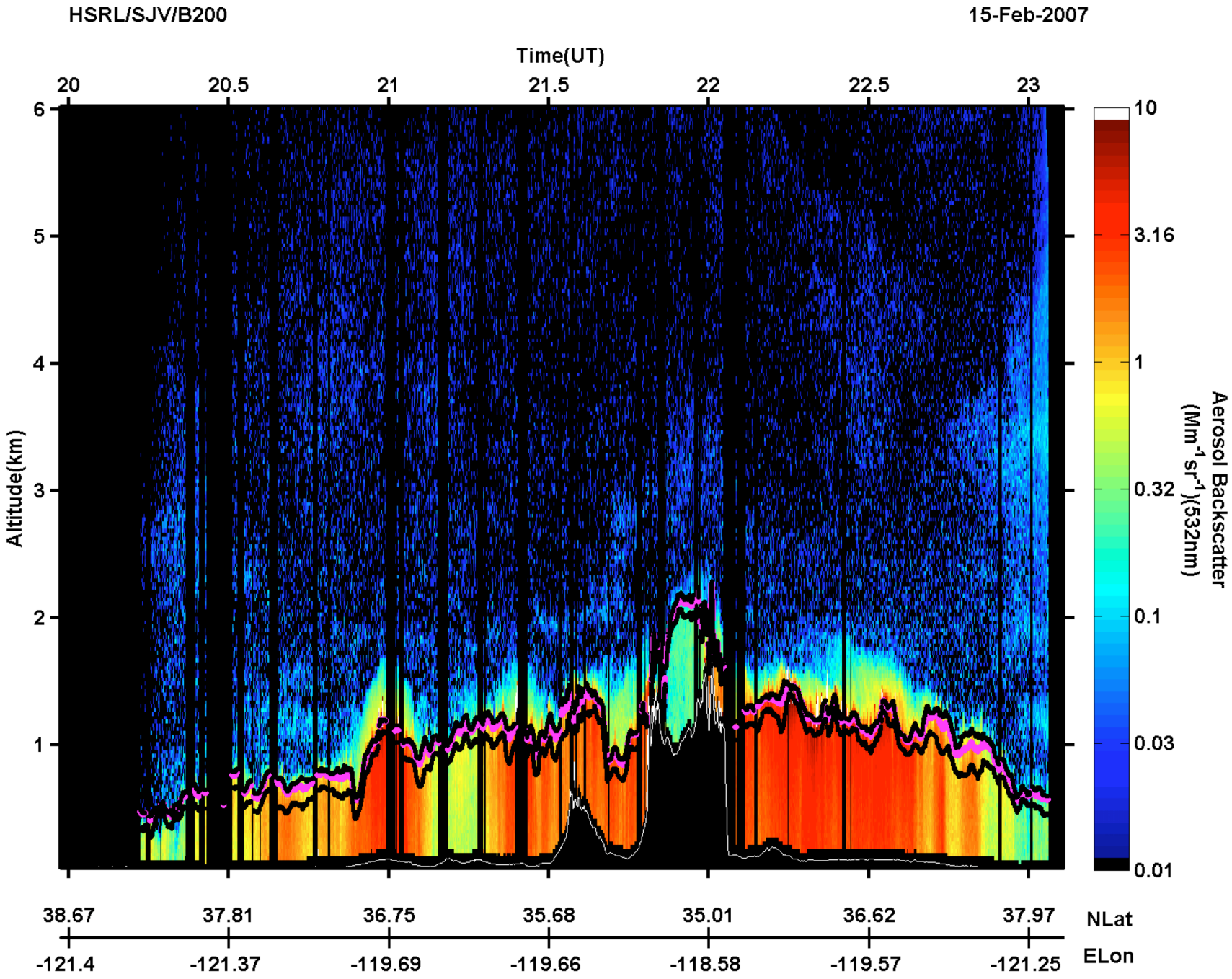
5) Near-surface extinction of lidar measurements result in similar statistics of linear regression as $AOD_{AERONET}$/HLH with PM2.5

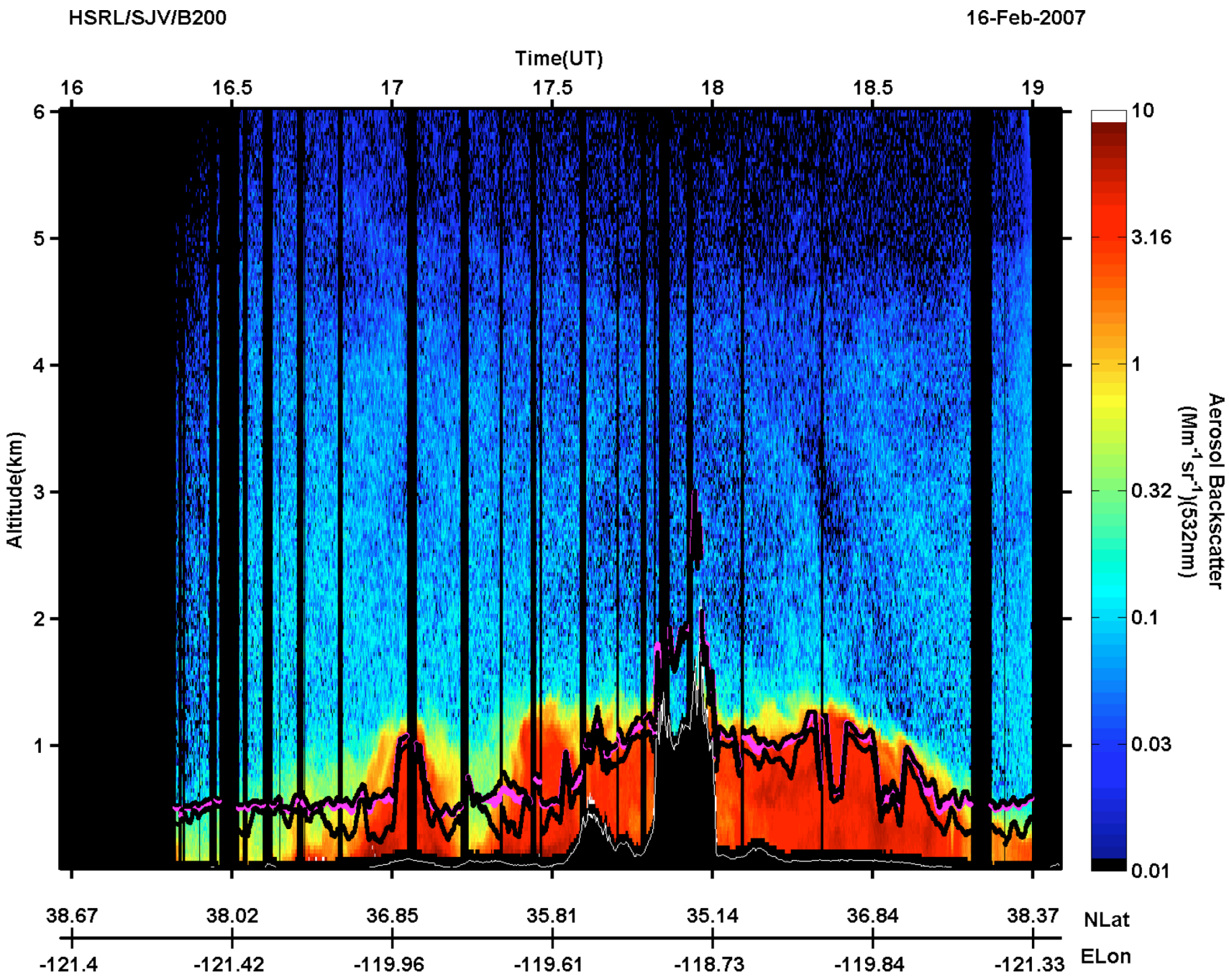
HSRL Aerosol Extinction Serve as Alternative Ground Truth Measurements of Surface Particulate Matter

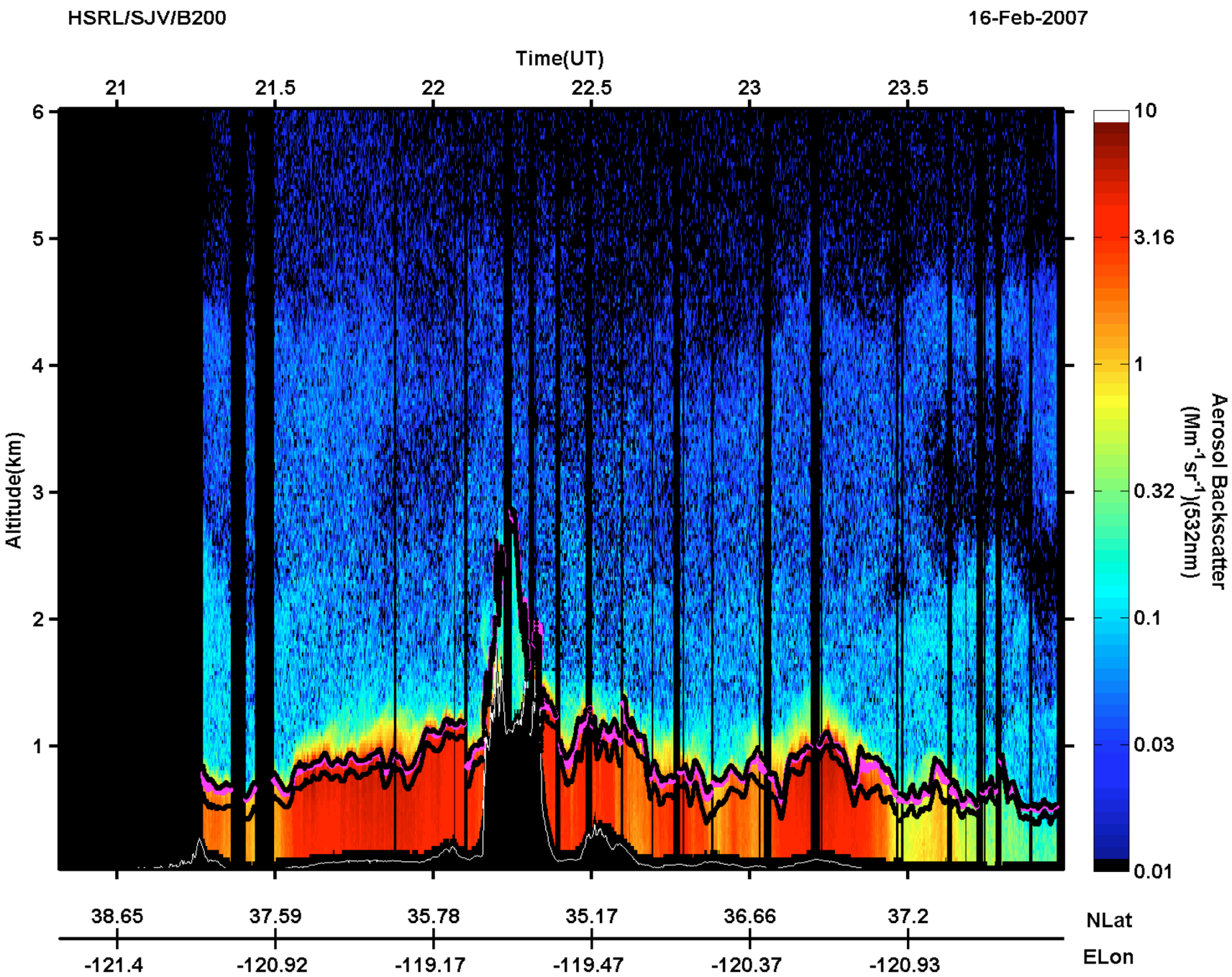
HSRL onboard NASA King Air Flight Track in SJV for February 2007 Intensive Observation

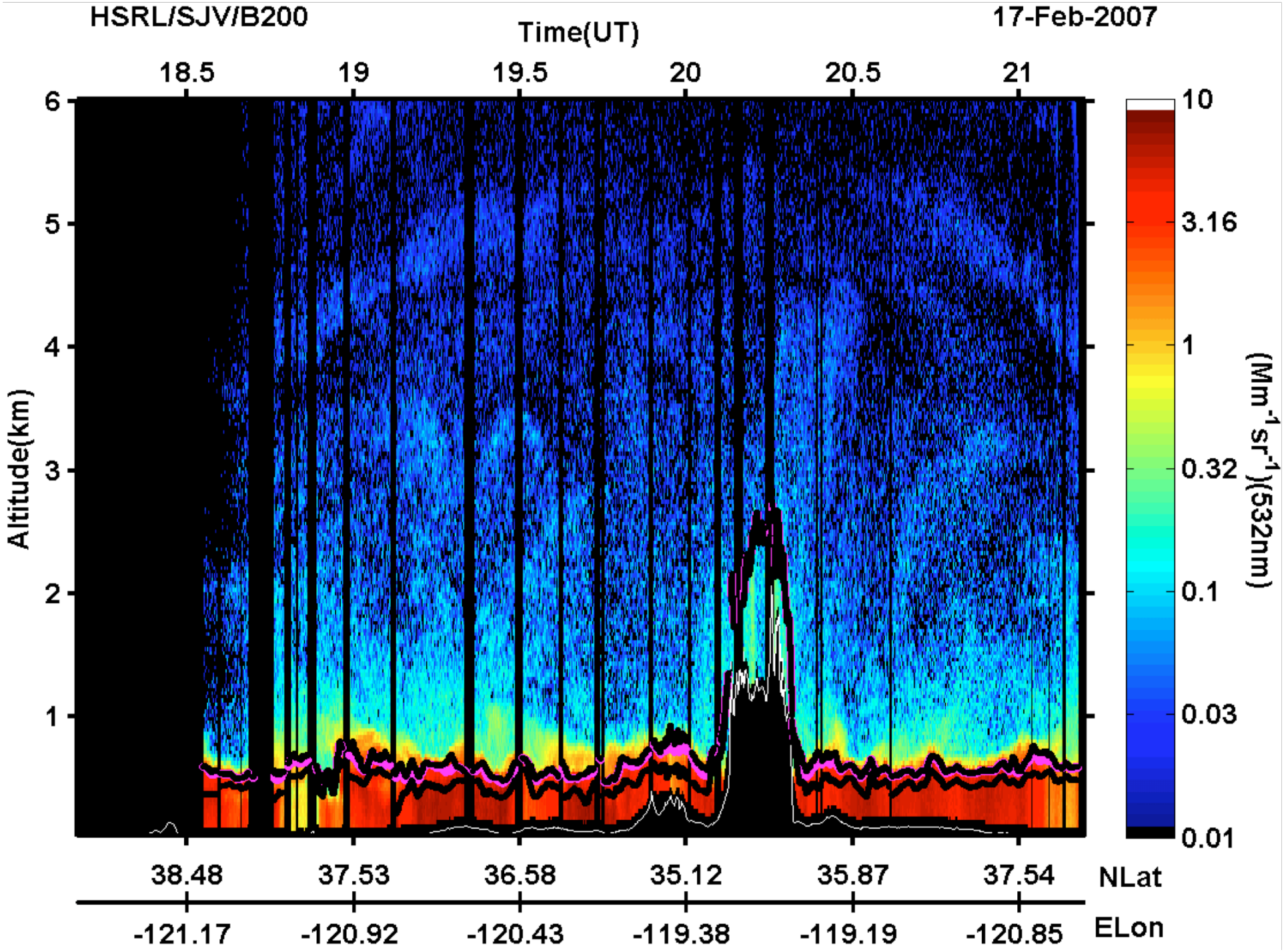


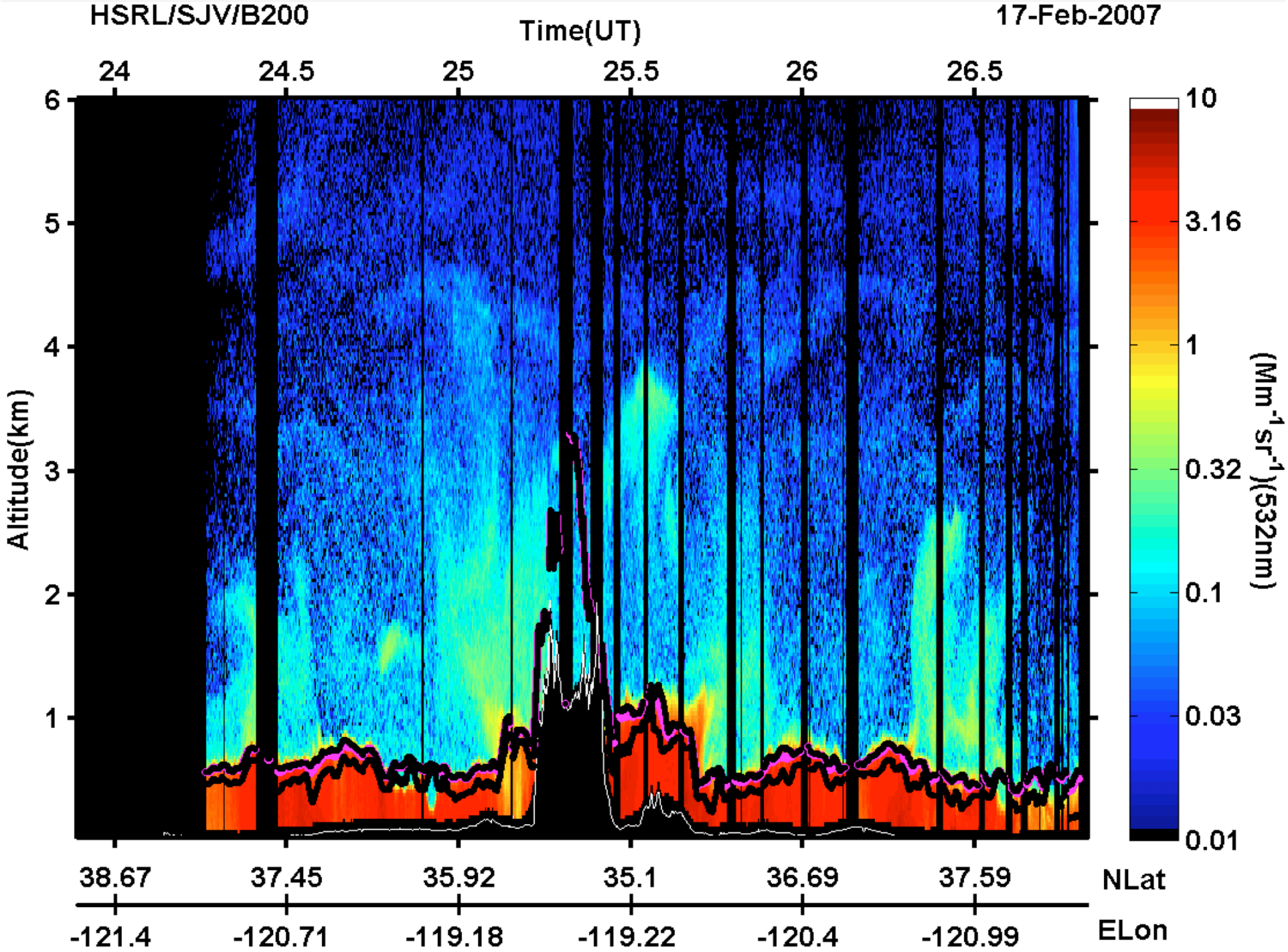

HSRL/SJV/B200
14-Feb-2007
Time(UT)
17.5
18
18.5
19
19.5
20
20.5
21
Altitude(km)
6
5
4
3
2
1
10
3.16
1
0.32
0.1
0.03
0.01
Aerosol Backscatter
(Mm-1 sr-1)(532nm)
38.68
37.76
36.34
34.63
35.37
36.39
37.01
38.11
NLat
-121.4
-121.1
-119.36
-118.06
-119.68
-120.22
-120.66
-121.57
ELon


HSRL/SJV/B200
15-Feb-2007
Time(UT)
20
20.5
21
21.5
22
22.5
23
Altitude(km)
6
5
4
3
2
1
10
3.16
1
0.32
0.1
0.03
0.01
Aerosol Backscatter
(Mm-1sr-1)(532nm)
38.67
37.81
36.75
35.68
35.01
36.62
37.97
NLat
-121.4
-121.37
-119.69
-119.66
-118.58
-119.57
-121.25
ELon


HSRL/SJV/B200
16-Feb-2007
Time(UT)
16
16.5
17
17.5
18
18.5
19
Altitude(km)
6
5
4
3
2
1
10
3.16
1
0.32
0.1
0.03
0.01
Aerosol Backscatter
(Mm-1sr-1)(532nm)
38.67
38.02
36.85
35.81
35.14
36.84
38.37
NLat
-121.4
-121.42
-119.96
-119.61
-118.73
-119.84
-121.33
ELon

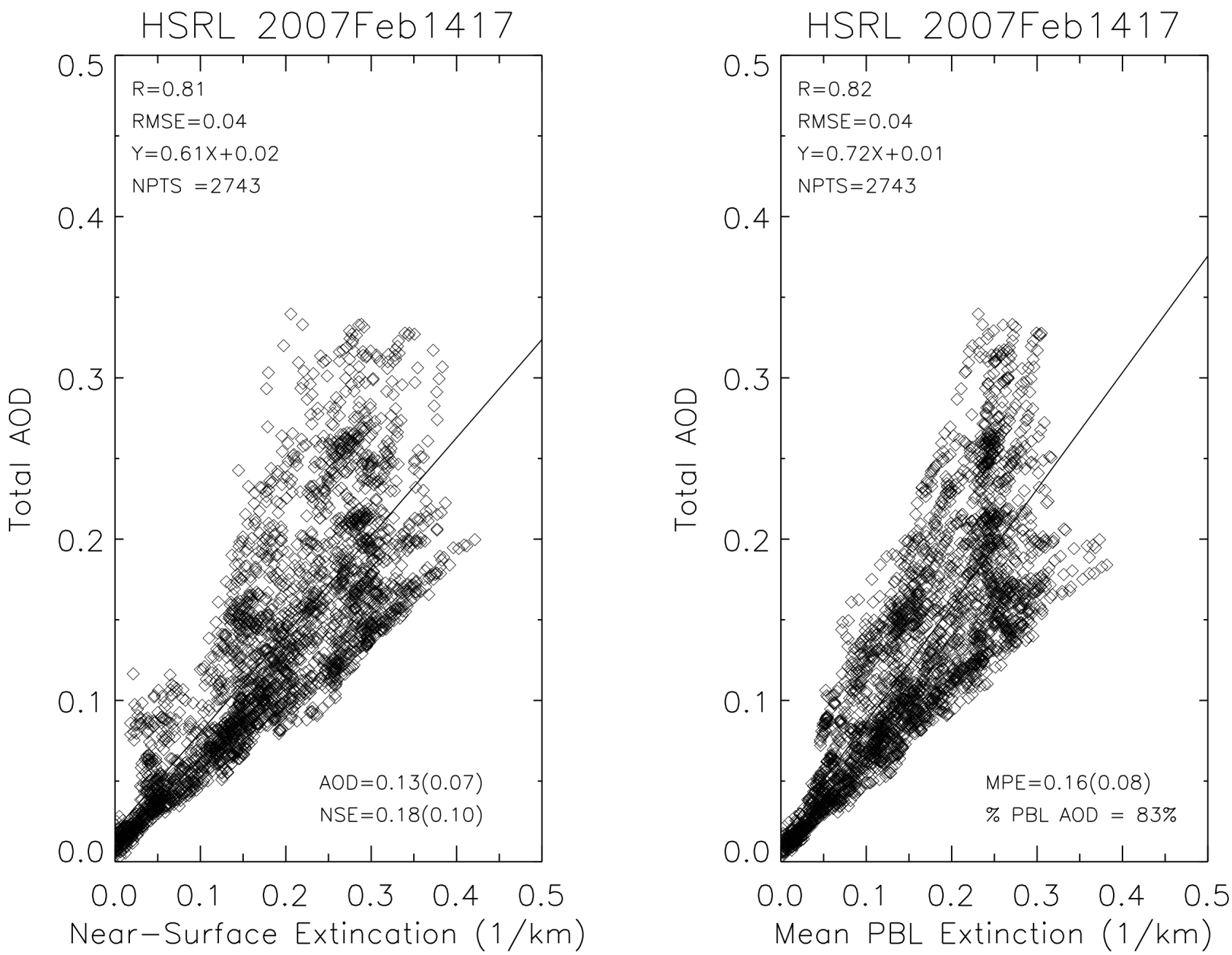

HSRL/SJV/B200
16-Feb-2007
Time(UT)
21
21.5
22
22.5
23
23.5
Altitude(km)
6
5
4
3
2
1
10
3.16
1
0.32
0.1
0.03
0.01
Aerosol Backscatter
(Mm-1 sr-1)(532nm)
38.65
37.59
35.78
35.17
36.66
37.2
NLat
-121.4
-120.92
-119.17
-119.47
-120.37
-120.93
ELon

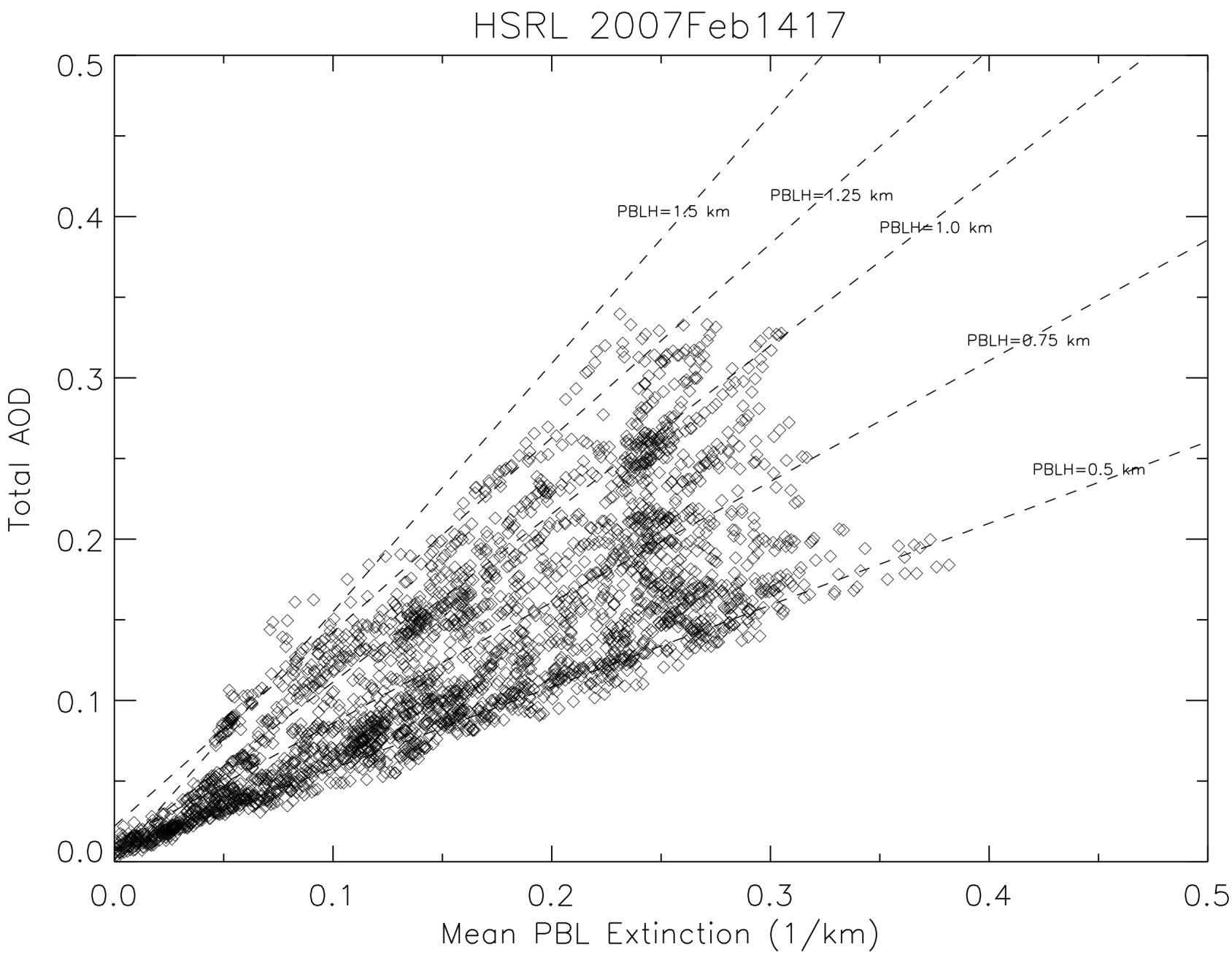

HSRL/SJV/B200
Time(UT)
17-Feb-2007
18.5
19
19.5
20
20.5
21
Altitude(km)
6
5
4
3
2
1
10
3.16
1
0.32
0.1
0.03
0.01
(Mm-1sr-1)(532nm)
38.48
37.53
36.58
35.12
35.87
37.54
NLat
-121.17
-120.92
-120.43
-119.38
-119.19
-120.85
ELon

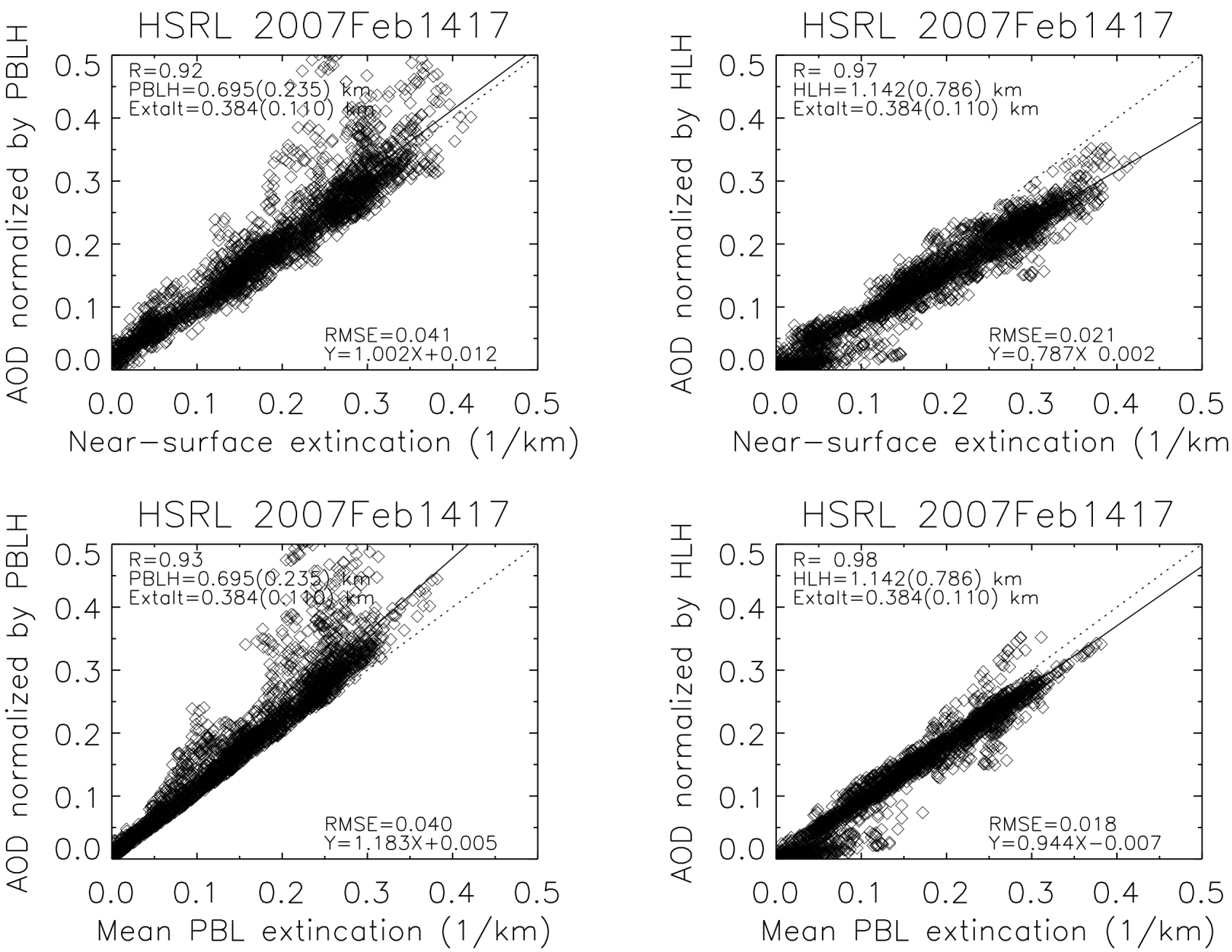

HSRL/SJV/B200
Time(UT)
17-Feb-2007
24
24.5
25
25.5
26
26.5
Altitude(km)
6
5
4
3
2
1
10
3.16
1
0.32
0.1
0.03
0.01
(Mm-1sr-1)(532nm)
38.67
37.45
35.92
35.1
36.69
37.59
NLat
-121.4
-120.71
-119.18
-119.22
-120.4
-120.99
ELon

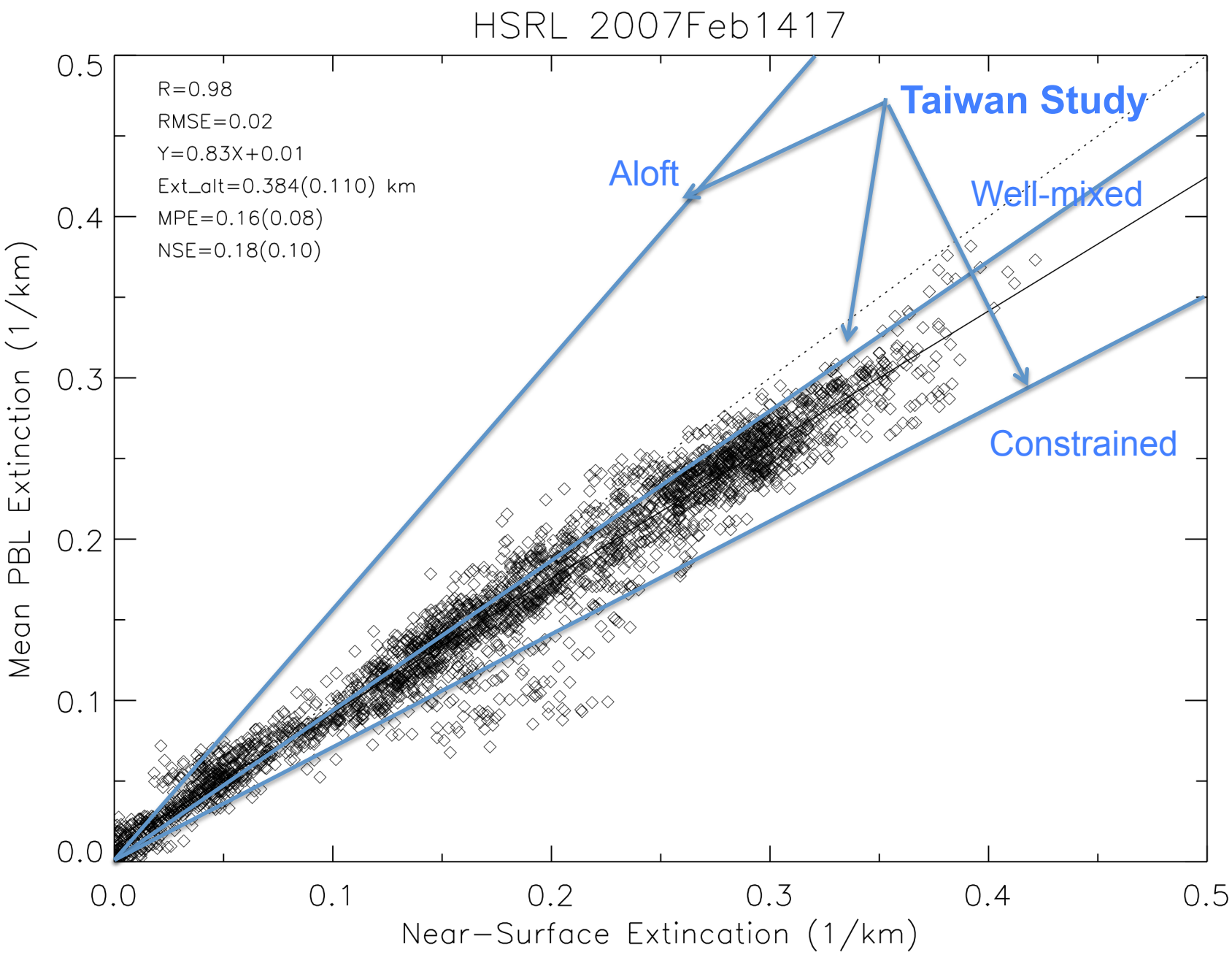
Linear Regression of HSRL AOD and Near-Surface Extinction in SJV 2007

Date	Slope	Intercept	R	PBLH (km)	% AOD below PBLH	RMSE	NPTS
Feb 14-17	0.61	0.02	0.81	0.695	83	0.04	2743
Feb 14	0.59	0.03	0.92	0.802	71	0.02	448
Feb 15	1.55	-0.01	0.89	1.025	91	0.03	223
Feb 16_L1	0.76	0.01	0.88	0.676	77	0.04	548
Feb 16_L2	0.81	-0.02	0.96	0.788	89	0.02	485
Feb 17_L1	0.46	0.01	0.96	0.503	88	0.01	520
Feb 17_L2	0.60	0.00	0.92	0.600	84	0.01	519


HSRL 2007Feb1417
R=0.81
RMSE=0.04
Y=0.61X+0.02
NPTS =2743
AOD=0.13(0.07)
NSE=0.18(0.10)
Total AOD
Near−Surface Extincation (1/km)
0.0
0.1
0.2
0.3
0.4
0.5
HSRL 2007Feb1417
R=0.82
RMSE=0.04
Y=0.72X+0.01
NPTS=2743
MPE=0.16(0.08)
% PBL AOD = 83%
Total AOD
Mean PBL Extinction (1/km)


HSRL 2007Feb1417
PBLH=1.5 km
PBLH=1.25 km
PBLH=1.0 km
PBLH=0.75 km
PBLH=0.5 km
Total AOD
Mean PBL Extinction (1/km)
0.0
0.1
0.2
0.3
0.4
0.5

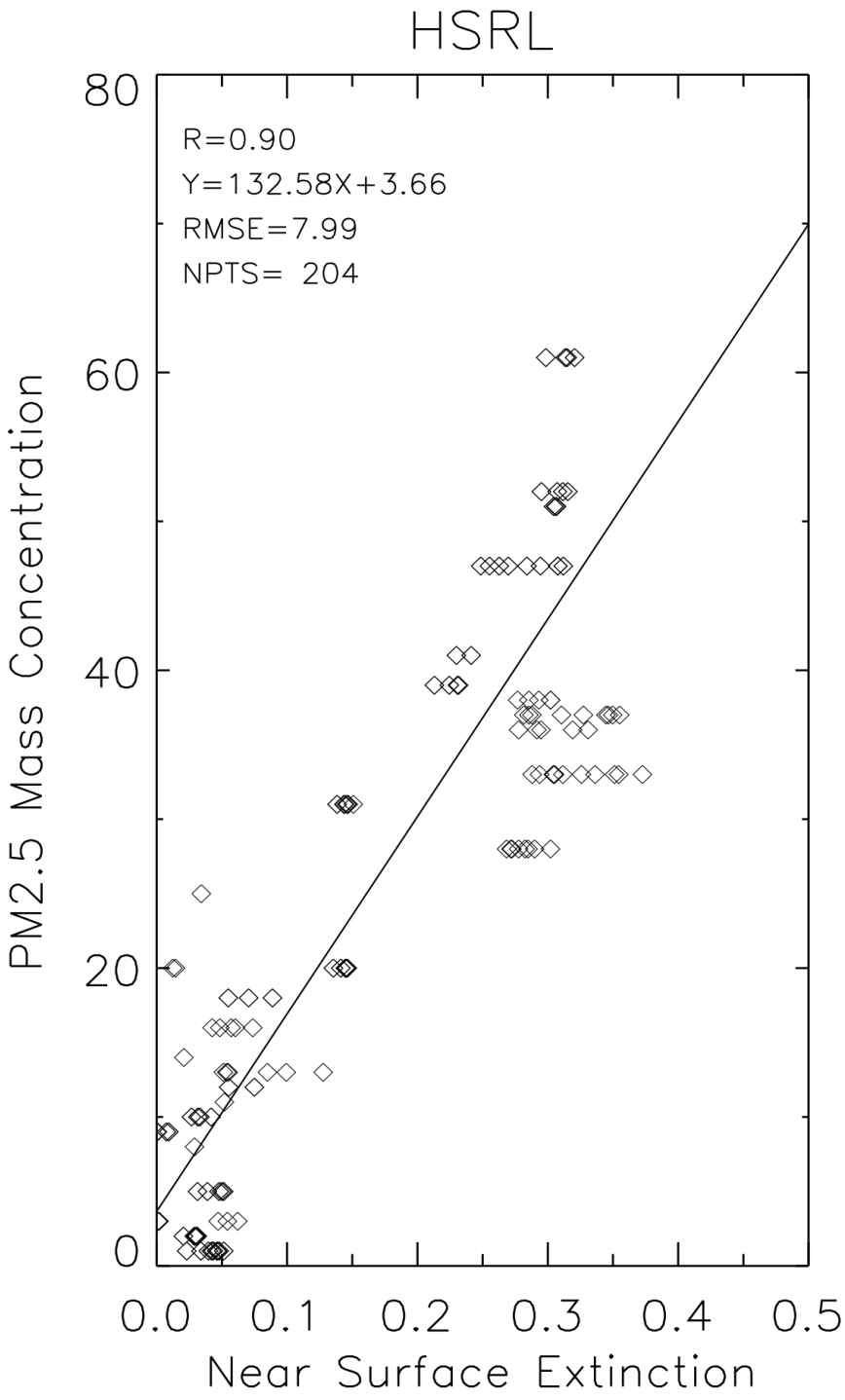

HSRL 2007Feb1417
R=0.92
PBLH=0.695(0.235) km
Extalt=0.384(0.110) km
RMSE=0.041
Y=1.002X+0.012
AOD normalized by PBLH
Near−surface extincation (1/km)
HSRL 2007Feb1417
R= 0.97
HLH=1.142(0.786) km
Extalt=0.384(0.110) km
RMSE=0.021
Y=0.787X 0.002
AOD normalized by HLH
Near−surface extincation (1/km
HSRL 2007Feb1417
R=0.93
PBLH=0.695(0.235) km
Extalt=0.384(0.110) km
RMSE=0.040
Y=1.183X+0.005
AOD normalized by PBLH
Mean PBL extincation (1/km)
HSRL 2007Feb1417
R= 0.98
HLH=1.142(0.786) km
Extalt=0.384(0.110) km
RMSE=0.018
Y=0.944X−0.007
AOD normalized by HLH
Mean PBL extincation (1/km)

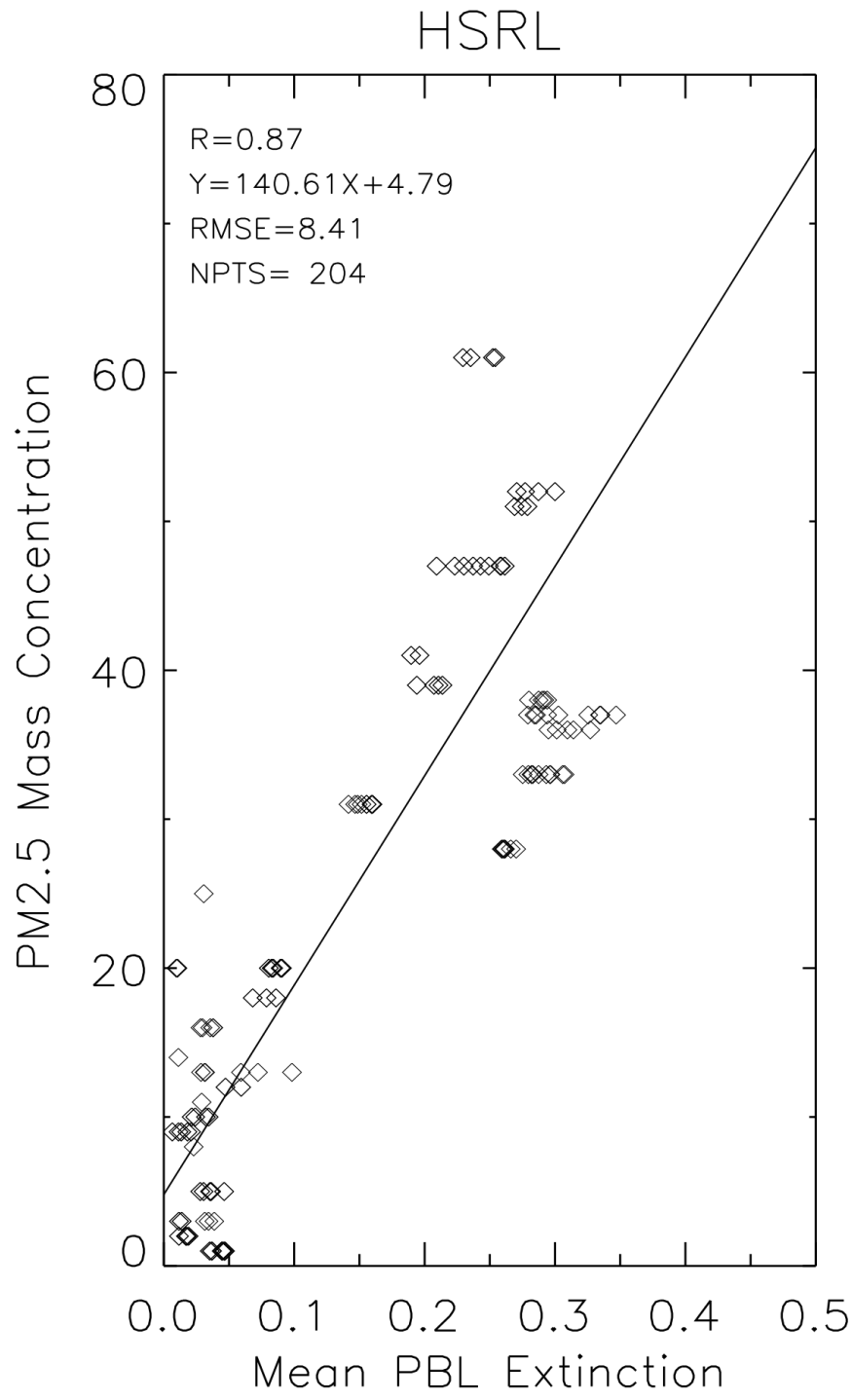

HSRL 2007Feb1417
R=0.98
RMSE=0.02
Y=0.83X+0.01
Ext_alt=0.384(0.110) km
MPE=0.16(0.08)
NSE=0.18(0.10)
Taiwan Study
Aloft
Well-mixed
Constrained
Mean PBL Extinction (1/km)
Near-Surface Extincation (1/km)
0.0
0.1
0.2
0.3
0.4
0.5

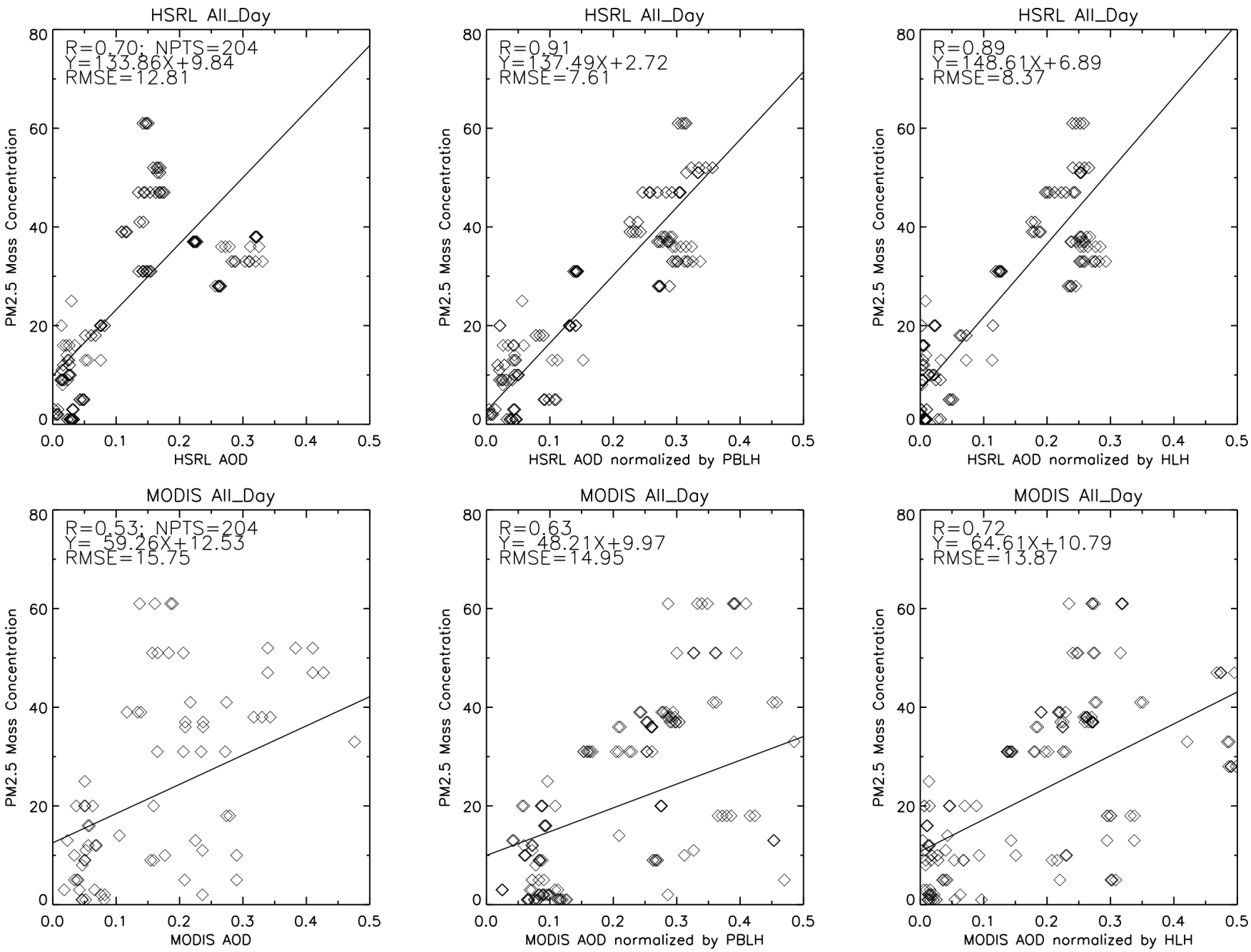
Improvement of Correlation by Accounting for PBL and Haze Layer Height

Date	R1	R2	R3	PBLH (km)	HLH (km)
Feb 14-17	0.81	0.92	0.97	0.695±0.235	1.142±0.789
Feb 14	0.92	0.98	0.93	0.802±0.318	1.756±1.144
Feb 15	0.89	0.94	0.93	1.025±0.170	1.258±0.290
Feb 16_L1	0.88	0.87	0.97	0.676±0.208	1.270±0.789
Feb 16_L2	0.96	0.99	0.98	0.788±0.138	1.190±0.701
Feb 17_L1	0.96	0.97	0.98	0.503±0.063	0.710±0.361
Feb 17_L2	0.92	0.90	0.92	0.589±0.118	0.818±0.447

R1: PM2.5 & AOD; R2: PM2.5 & AOD/PBLH; R3: PM2.5 & AOD/HLH


HSRL
R=0.90
Y=132.58X+3.66
RMSE=7.99
NPTS= 204
PM2.5 Mass Concentration
Near Surface Extinction
0
20
40
60
80
0.0
0.1
0.2
0.3
0.4
0.5


HSRL
R=0.87
Y=140.61X+4.79
RMSE=8.41
NPTS= 204
PM2.5 Mass Concentration
Mean PBL Extinction
0
20
40
60
80
0.0
0.1
0.2
0.3
0.4
0.5


HSRL All_Day
R=0.70; NPTS=204
Y=133.86X+9.84
RMSE=12.81
PM2.5 Mass Concentration
HSRL AOD
HSRL All_Day
R=0.91
Y=137.49X+2.72
RMSE=7.61
PM2.5 Mass Concentration
HSRL AOD normalized by PBLH
HSRL All_Day
R=0.89
Y=148.61X+6.89
RMSE=8.37
PM2.5 Mass Concentration
HSRL AOD normalized by HLH
MODIS All_Day
R=0.53; NPTS=204
Y= 59.26X+12.53
RMSE=15.75
PM2.5 Mass Concentration
MODIS AOD
MODIS All_Day
R=0.63
Y= 48.21X+9.97
RMSE=14.95
PM2.5 Mass Concentration
MODIS AOD normalized by PBLH
MODIS All_Day
R=0.72
Y= 64.61X+10.79
RMSE=13.87
PM2.5 Mass Concentration
MODIS AOD normalized by HLH

- HSRL provides AOD, PBLH, and aerosol extinction profile measurements serve as alternative ground truth in estimating surface PM (R~0.9 for near-surface extinction vs. PM2.5)

- HSRL produces aerosol extinction measurements along flight tracks (as opposed to point sources, sunphotometer and PM), which better characterize spatial variation of aerosol in relating to PM within a region

- HSRL is really a beautiful data set.

For Field Experiments:

- Provide near-real time MODIS RGB and AOD images over the designated regions

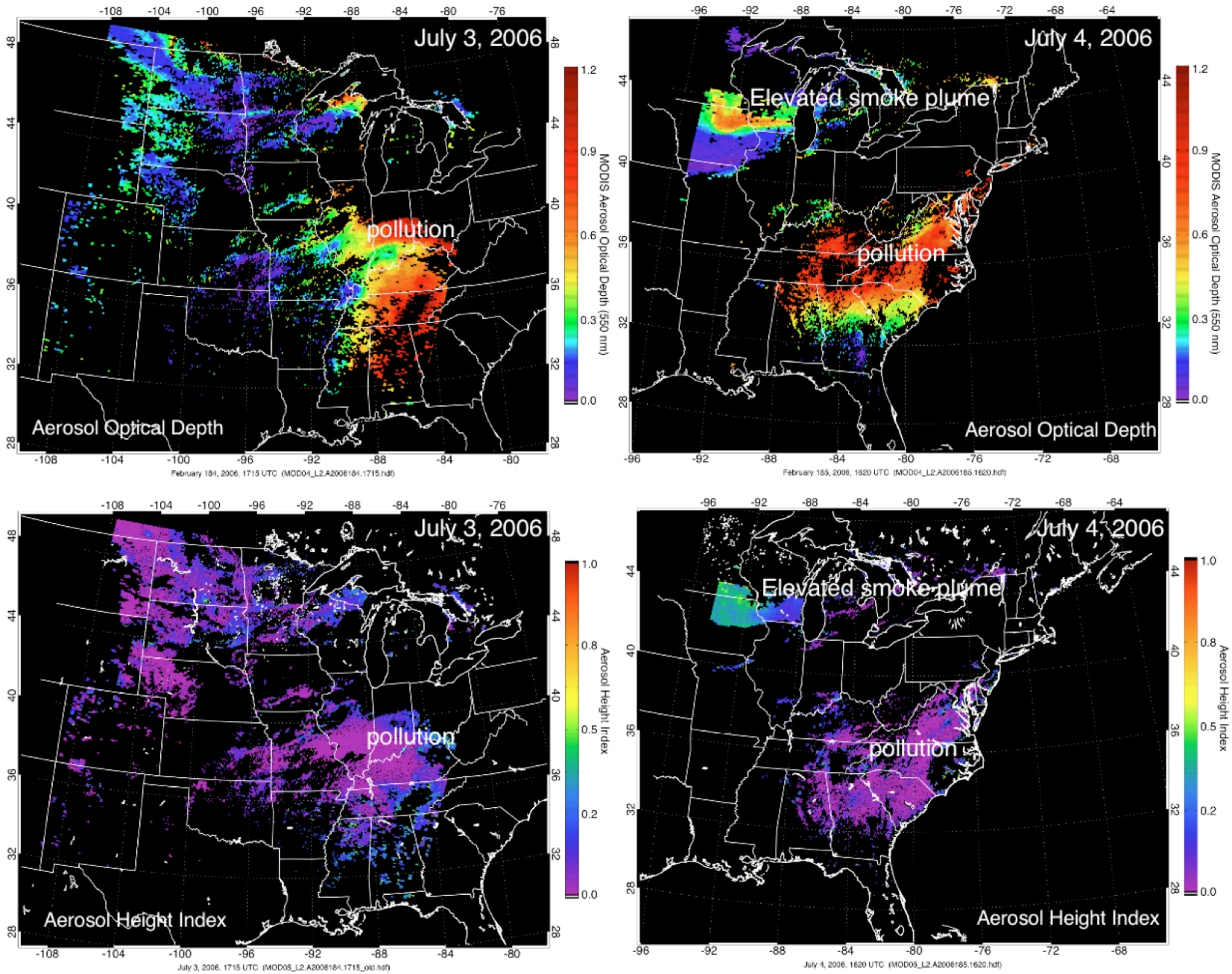
- Analyze daily MODIS AOD and AHI (Aerosol Height Index) data; AHI data will not be operationally available but will be available next day for distribution analysis with HSRL, MPLNet, and CALIPSO measurements

July 3, 2006

July 4, 2006

AOD

Aerosol Height Index

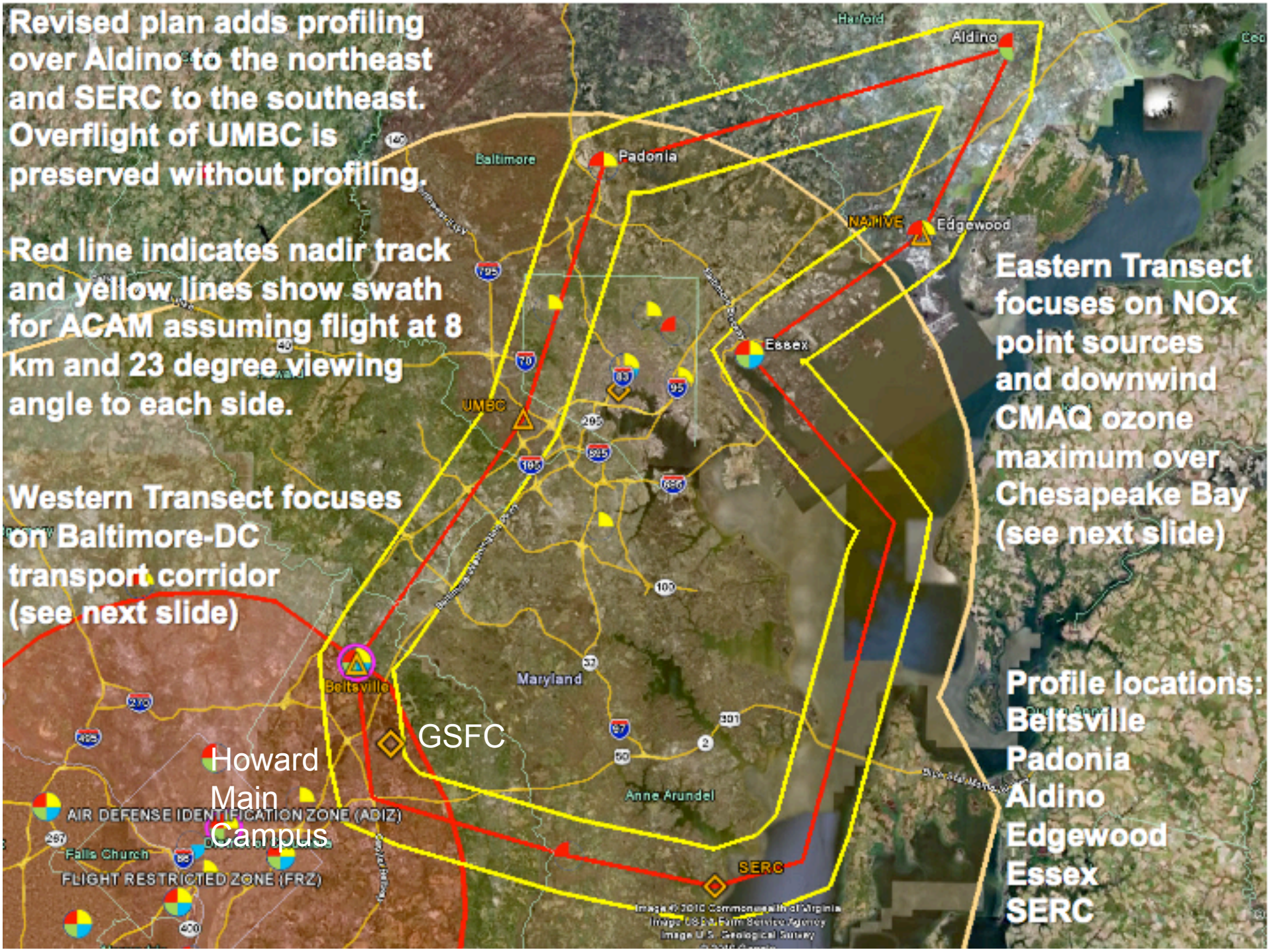


Need for Airborne Measurements 2011

- HSRL flying over
  Sunphotometer: AERONET (GSFC, 2010 no data?; SERC) + more (?)
  Lidar: MPLNet (GSFC, UMBC), Beltsville, NATIVE
  PM2.5: EPA-AQS (Howard U. Main Campus; not under flight path), Beltsville, Padonia, NATIVE, Essex

Distance:
GSFC-UMBC: 30 km
GSFC-Beltsville: 10 km
GSFC-Howard U. main campus: 20 km

*Importance of GSFC is the long-term sunphotometer and MPL measurements


Revised plan adds profiling over Aldino to the northeast and SERC to the southeast. Overflight of UMBC is preserved without profiling.
Red line indicates nadir track and yellow lines show swath for ACAM assuming flight at 8 km and 23 degree viewing angle to each side.
Western Transect focuses on Baltimore-DC transport corridor (see next slide)
Eastern Transect focuses on NOx point sources and downwind CMAQ ozone maximum over Chesapeake Bay (see next slide)
Profile locations:
Beltsville
Padonia
Aldino
Edgewood
Essex
SERC
Aldino
Padonia
Baltimore
NATIVE
Edgewood
Essex
UMBC
Beltsville
Maryland
GSFC
Howard
Main
Campus
Anne Arundel
AIR DEFENSE IDENTIFICATION ZONE (ADIZ)
Falls Church
FLIGHT RESTRICTED ZONE (FRZ)
SERC