Lidar: a Powerful Tool for Aerosol Transport Studies

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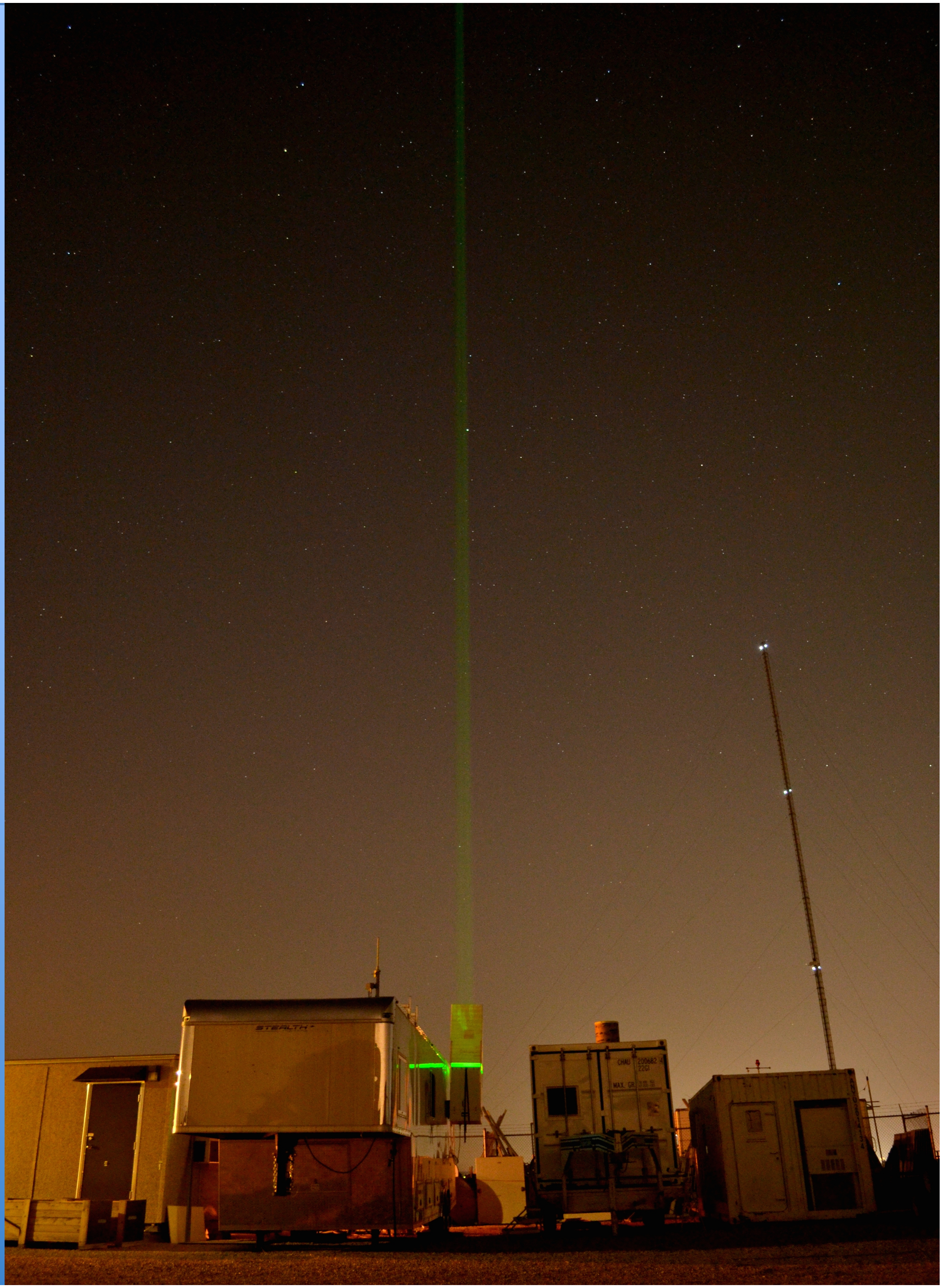
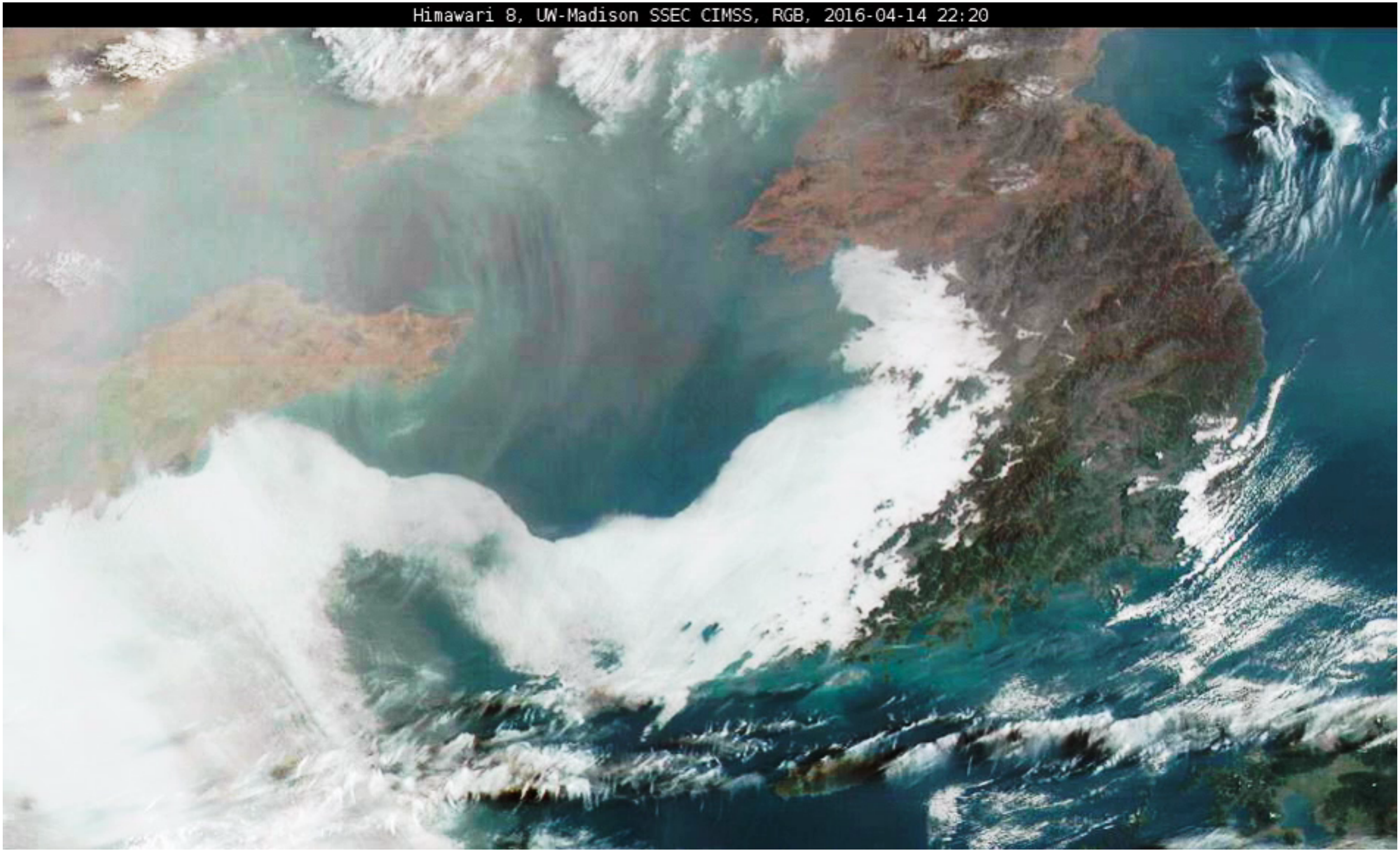
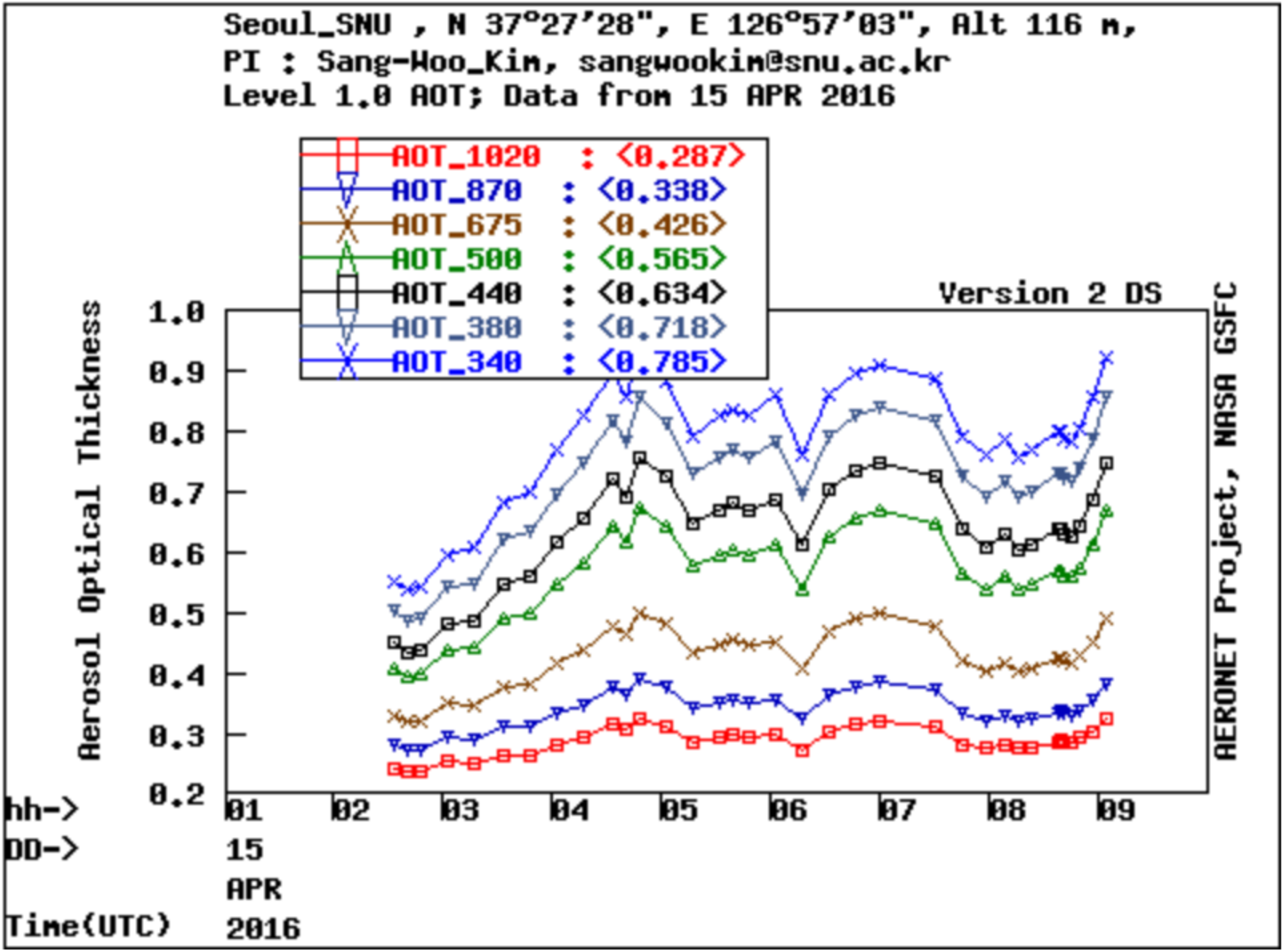
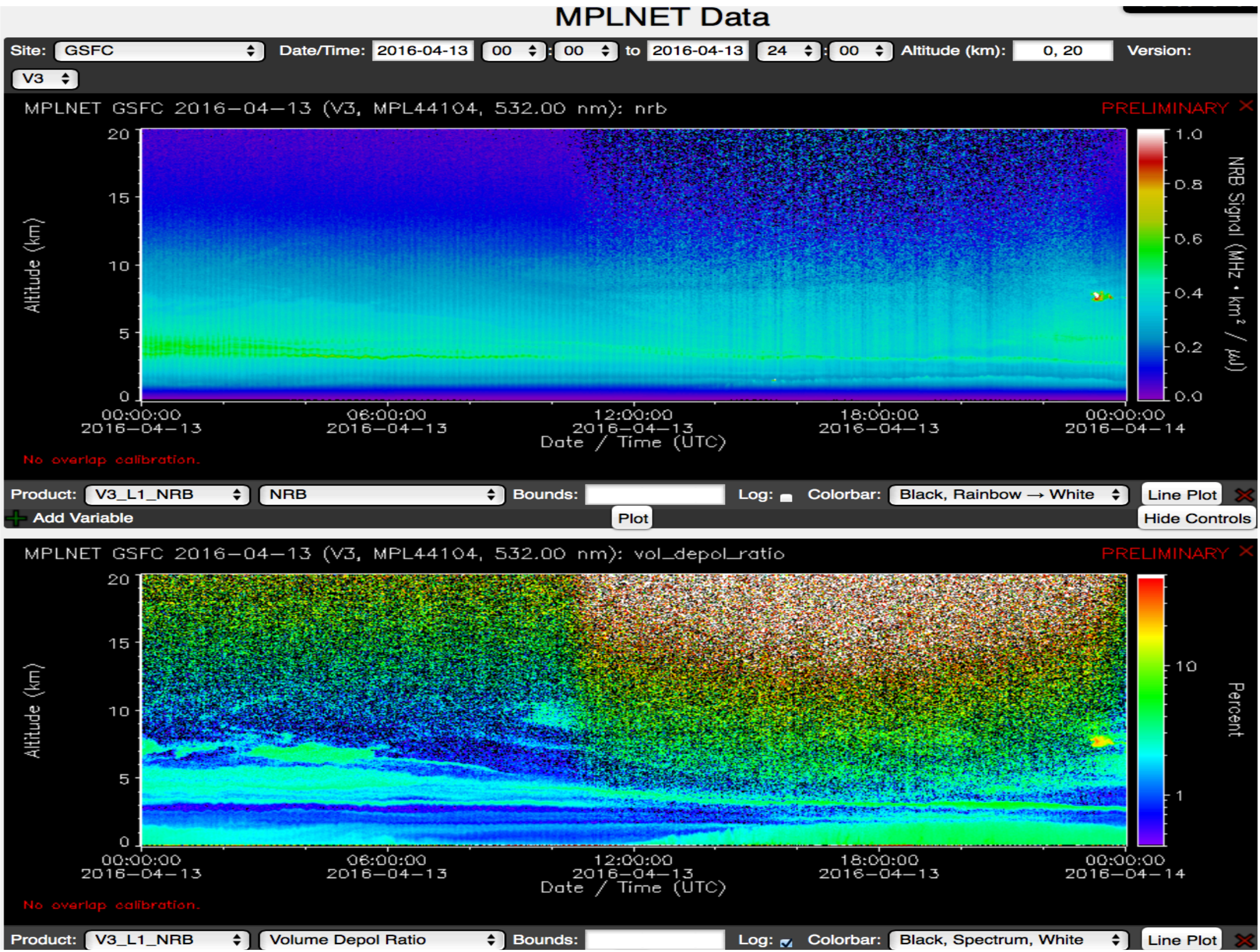



Himawari 8, UW-Madison SSEC CIMSS, RGB, 2016-04-14 22:20

AOD Level 1.0 data from APR 15 of 2016




ALGADE
IRSN


MPLNET Data
Site: GSFC
Date/Time: 2016-04-13 00 : 00 to 2016-04-13 24 : 00
Altitude (km): 0, 20
Version: V3
MPLNET GSFC 2016-04-13 (V3, MPL44104, 532.00 nm): nrb
PRELIMINARY
Altitude (km)
20
15
10
5
0
00:00:00 2016-04-13
06:00:00 2016-04-13
12:00:00 2016-04-13
18:00:00 2016-04-13
00:00:00 2016-04-14
Date / Time (UTC)
1.0
0.8
0.6
0.4
0.2
0.0
NRB Signal (MHz • km² / μJ)
No overlap calibration.
Product: V3_L1_NRB
NRB
Bounds:
Log:
Colorbar: Black, Rainbow → White
Line Plot
Add Variable
Plot
Hide Controls
MPLNET GSFC 2016-04-13 (V3, MPL44104, 532.00 nm): vol_depol_ratio
PRELIMINARY
Altitude (km)
20
15
10
5
0
00:00:00 2016-04-13
06:00:00 2016-04-13
12:00:00 2016-04-13
18:00:00 2016-04-13
00:00:00 2016-04-14
Date / Time (UTC)
10
1
Percent
No overlap calibration.
Product: V3_L1_NRB
Volume Depol Ratio
Bounds:
Log:
Colorbar: Black, Spectrum, White
Line Plot

Particle backscatter coefficient

$$\beta_{\mathrm{aer}}(R)+\beta_{\mathrm{mol}}(R)= \frac{S(R)\exp\left\{-2\int_{R_0}^{R}\left[L_{\mathrm{aer}}(r)-L_{\mathrm{mol}}\right]\beta_{\mathrm{mol}}(r)\,\mathrm{d}r\right\}}{\frac{S(R_0)}{\beta_{\mathrm{aer}}(R_0)+\beta_{\mathrm{mol}}(R_0)}-2\int_{R_0}^{R}L_{\mathrm{aer}}(r)S(r)\exp\left\{-2\int_{R_0}^{r}\left[L_{\mathrm{aer}}(r')-L_{\mathrm{mol}}\right]\beta_{\mathrm{mol}}(r')\,\mathrm{d}r'\right\}\mathrm{d}r}. \quad (11)$$

Particle extinction coefficient

$$\alpha_{\mathrm{aer}}(R)=L_{\mathrm{aer}}(R)\beta_{\mathrm{aer}}(R). \quad (12)$$

Input:

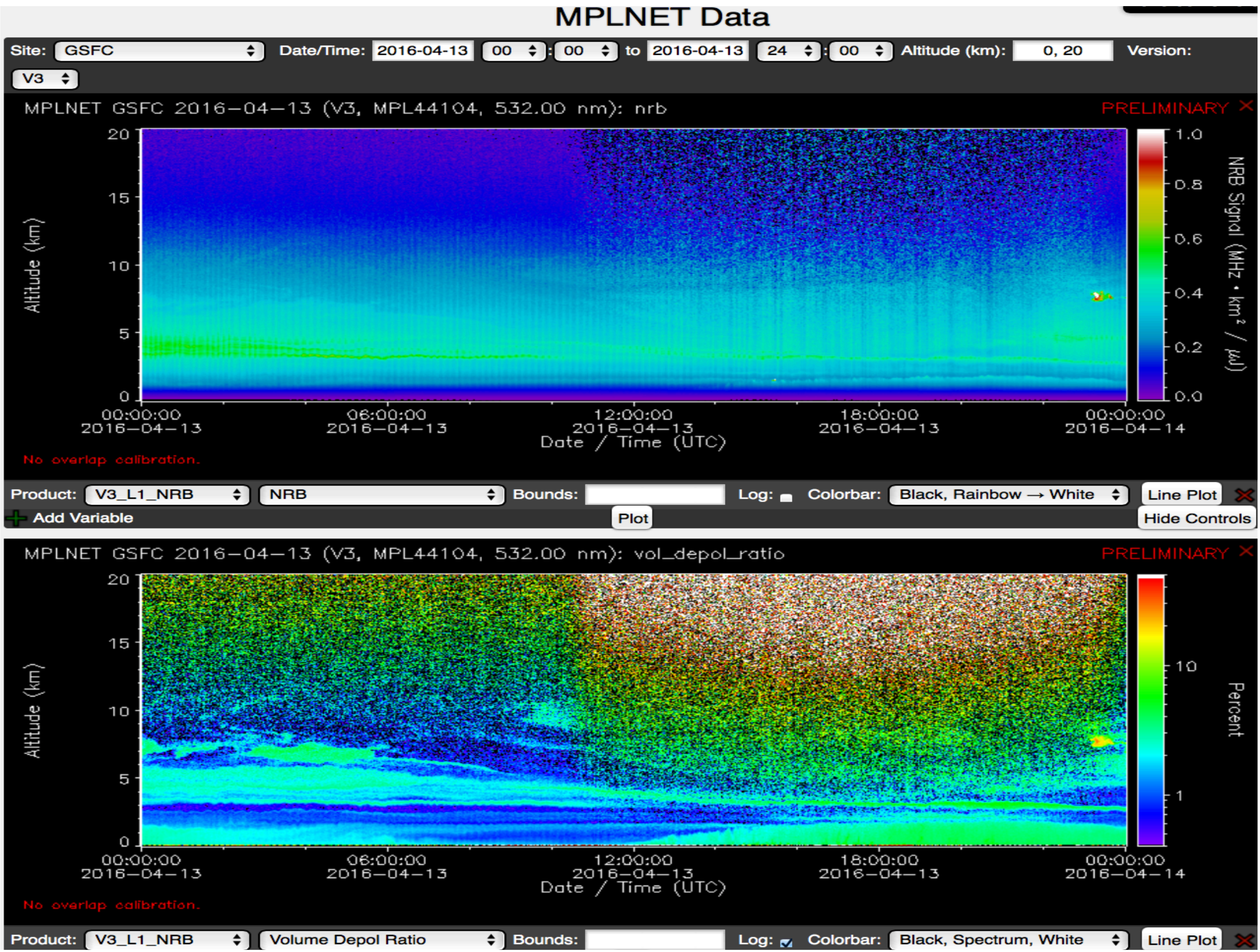
(1) reference backscatter coefficient (calibration)

(2) particle lidar ratio

(Typical values range 20 → 60)

Lidar: Range-Resolved Optical Remote Sensing of the Atmosphere, Weitkamp, Springer, 1999

Klett solution for backscatter and extinction cross section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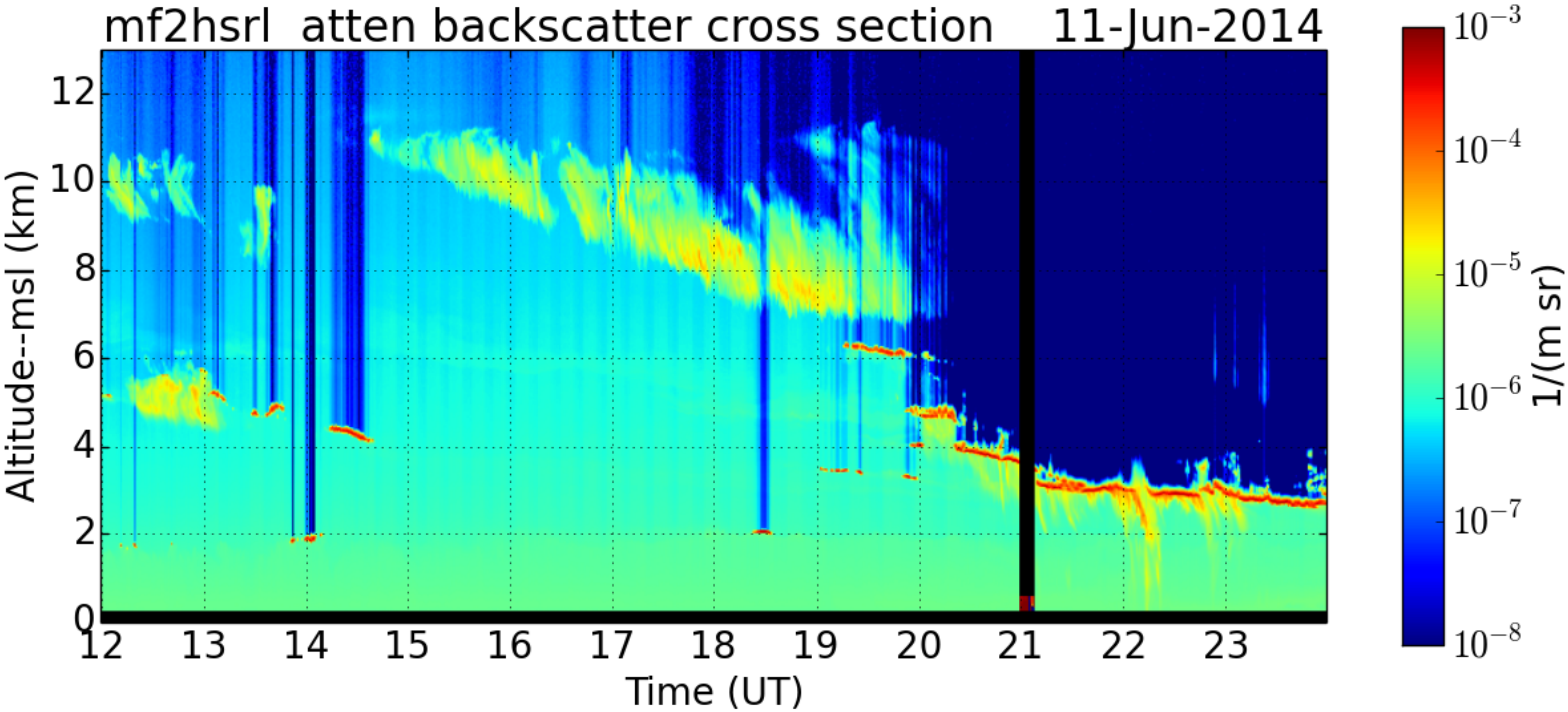
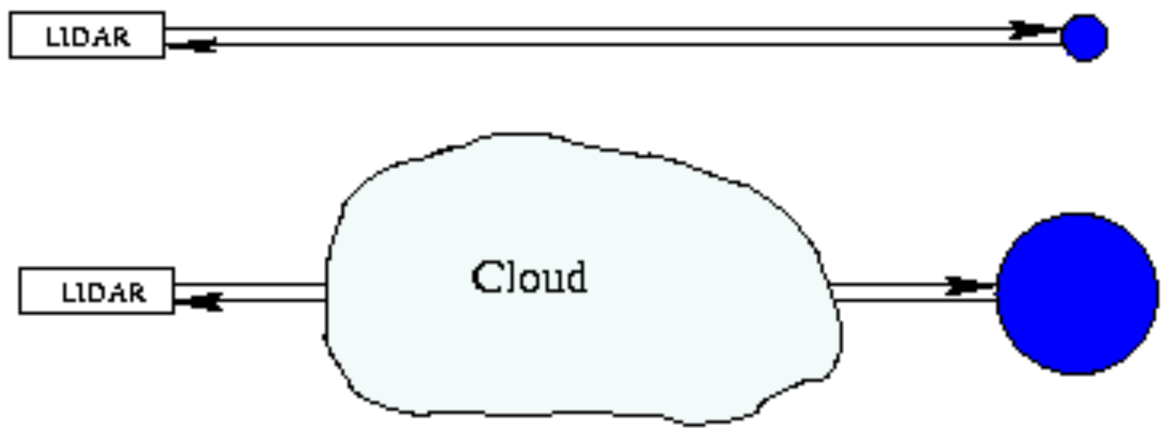
MPLNET GSFC 2016−04−13 (V3, MPL44104, 532.00 nm): nrb
PRELIMINARY
Altitude (km)
20
15
10
5
0
00:00:00 2016−04−13
06:00:00 2016−04−13
12:00:00 2016−04−13
18:00:00 2016−04−13
00:00:00 2016−04−14
Date / Time (UTC)
1.0
0.8
0.6
0.4
0.2
0.0
NRB Signal (MHz • km² / μJ)
No overlap calibration.
Product: V3_L1_NRB
NRB
Bounds:
Log:
Colorbar: Black, Rainbow → White
Line Plot
Add Variable
Plot
Hide Controls
MPLNET GSFC 2016−04−13 (V3, MPL44104, 532.00 nm): vol_depol_ratio
PRELIMINARY
Altitude (km)
20
15
10
5
0
00:00:00 2016−04−13
06:00:00 2016−04−13
12:00:00 2016−04−13
18:00:00 2016−04−13
00:00:00 2016−04−14
Date / Time (UTC)
10
1
Percent
No overlap calibration.
Product: V3_L1_NRB
Volume Depol Ratio
Bounds:
Log:
Colorbar: Black, Spectrum, White
Line Plot



mf2hsrl atten backscatter cross section
11-Jun-2014
Altitude--msl (km)
0
2
4
6
8
10
12
12
13
14
15
16
17
18
19
20
21
22
23
Time (UT)
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
1/(m sr)

$$p(r) \sim \frac{P(180,r)}{4\pi}\beta_s(r) \cdot e^{-2\int_0^r \beta_e(r)dr}$$



Traditional aerosol lidar can not distinguish between changes in target reflectivity and attenuation between the lidar and the target

Attenuation and geometric terms are the same

Power received from molecules:

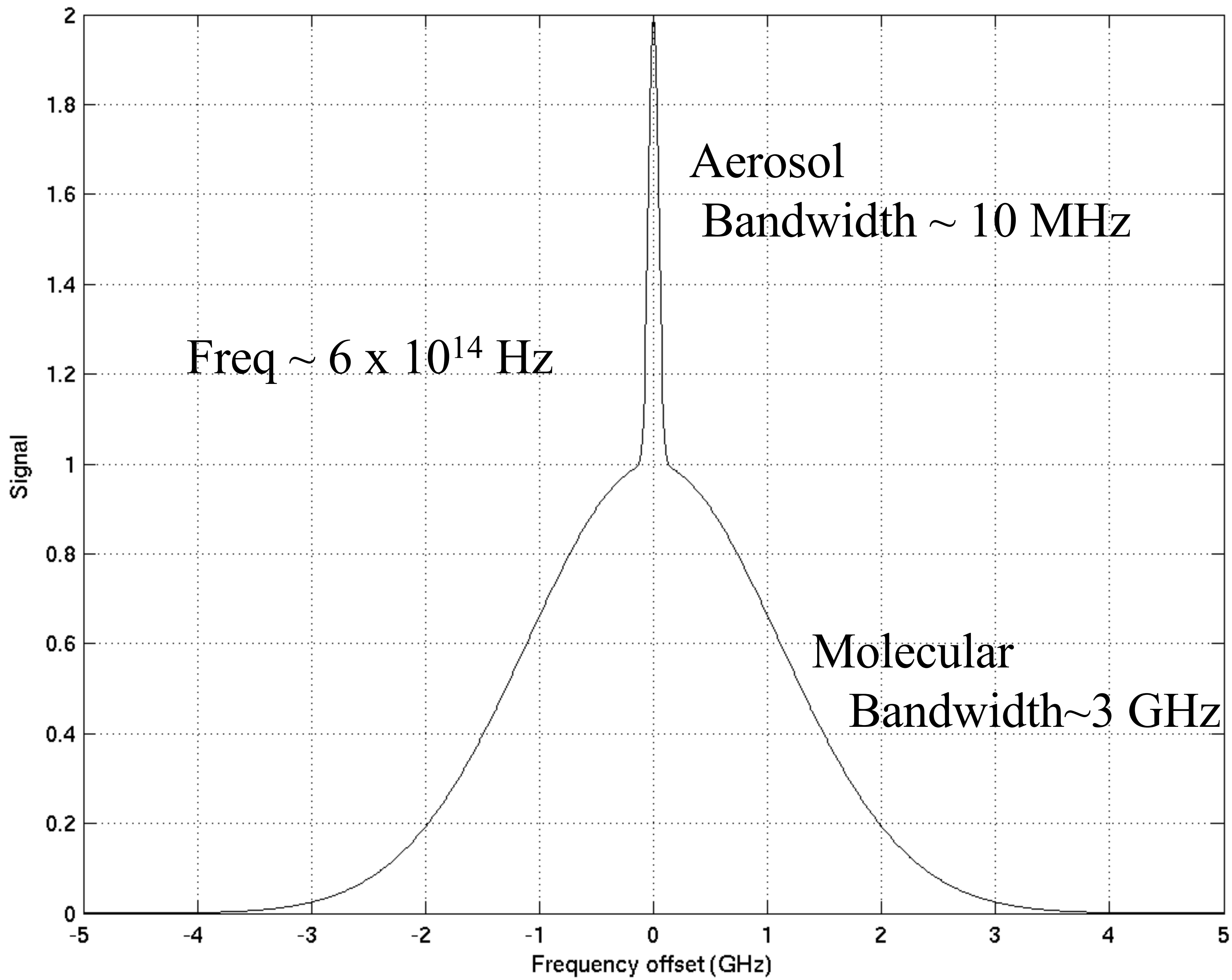
$$p_m(r) \sim g(r) \cdot \frac{1}{r^2} \cdot \frac{3}{8\pi} \cdots \cdot \beta_m(r) \cdot e^{-2\int_0^r (\beta_m(r)+\beta_{ea}(r))dr}$$

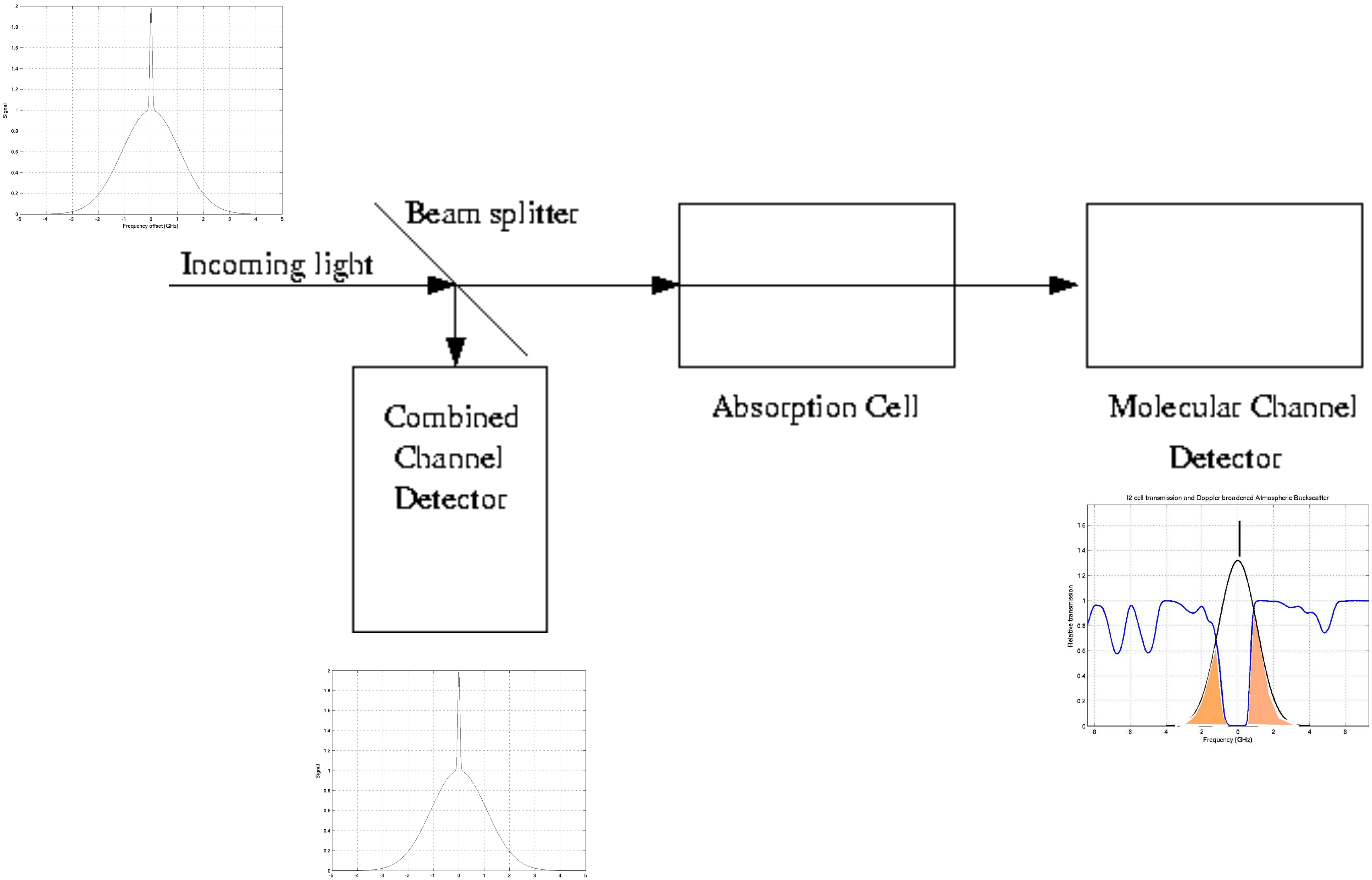
Power received from particulates:

$$p_a(r) \sim g(r) \cdot \frac{1}{r^2} \cdot \frac{P(180,r)}{4\pi} \cdots \cdot \beta_{sa}(r) \cdot e^{-2\int_0^r (\beta_m(r)+\beta_{ea}(r))dr}$$

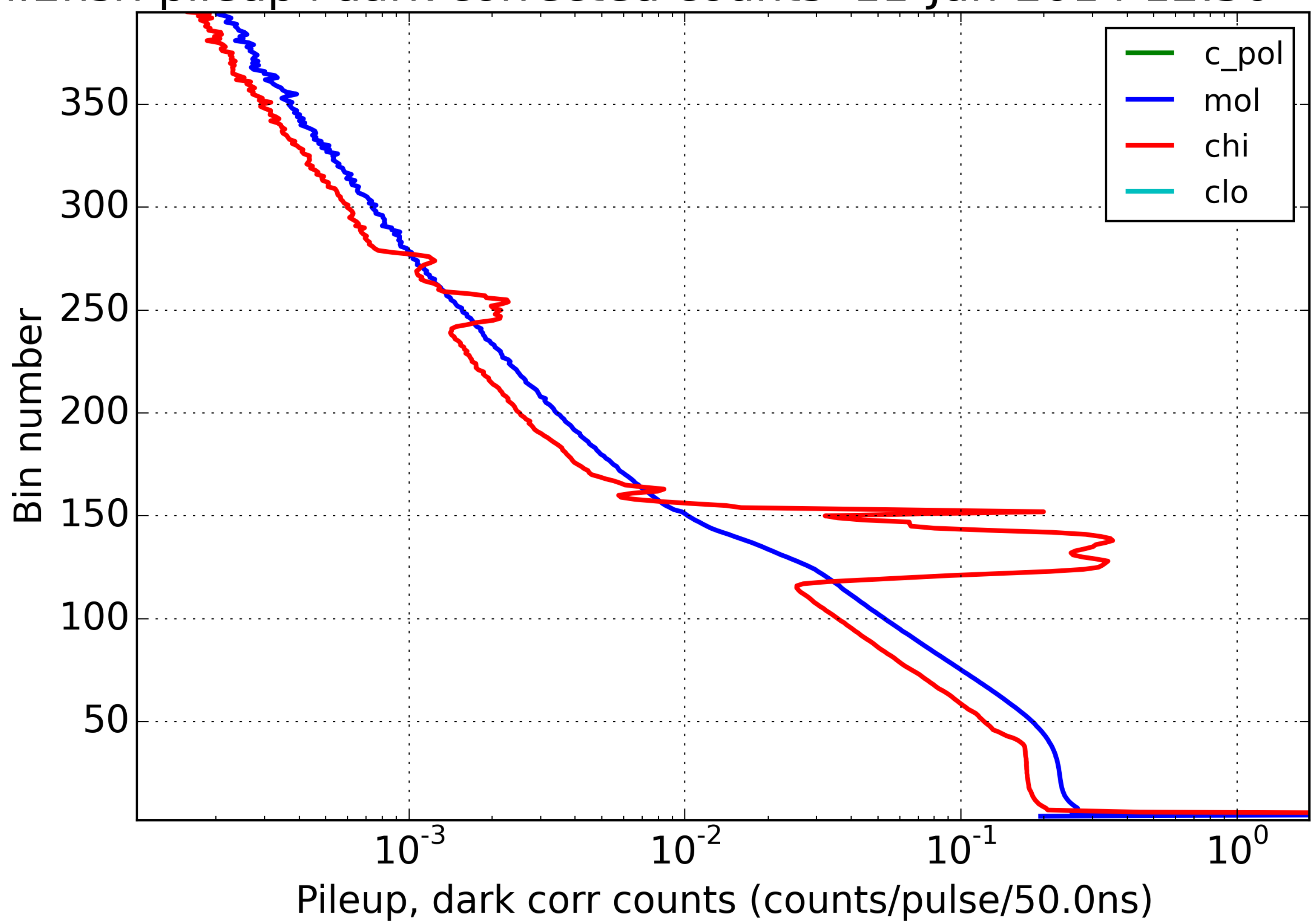
Dividing the particulate return by the aerosol return:

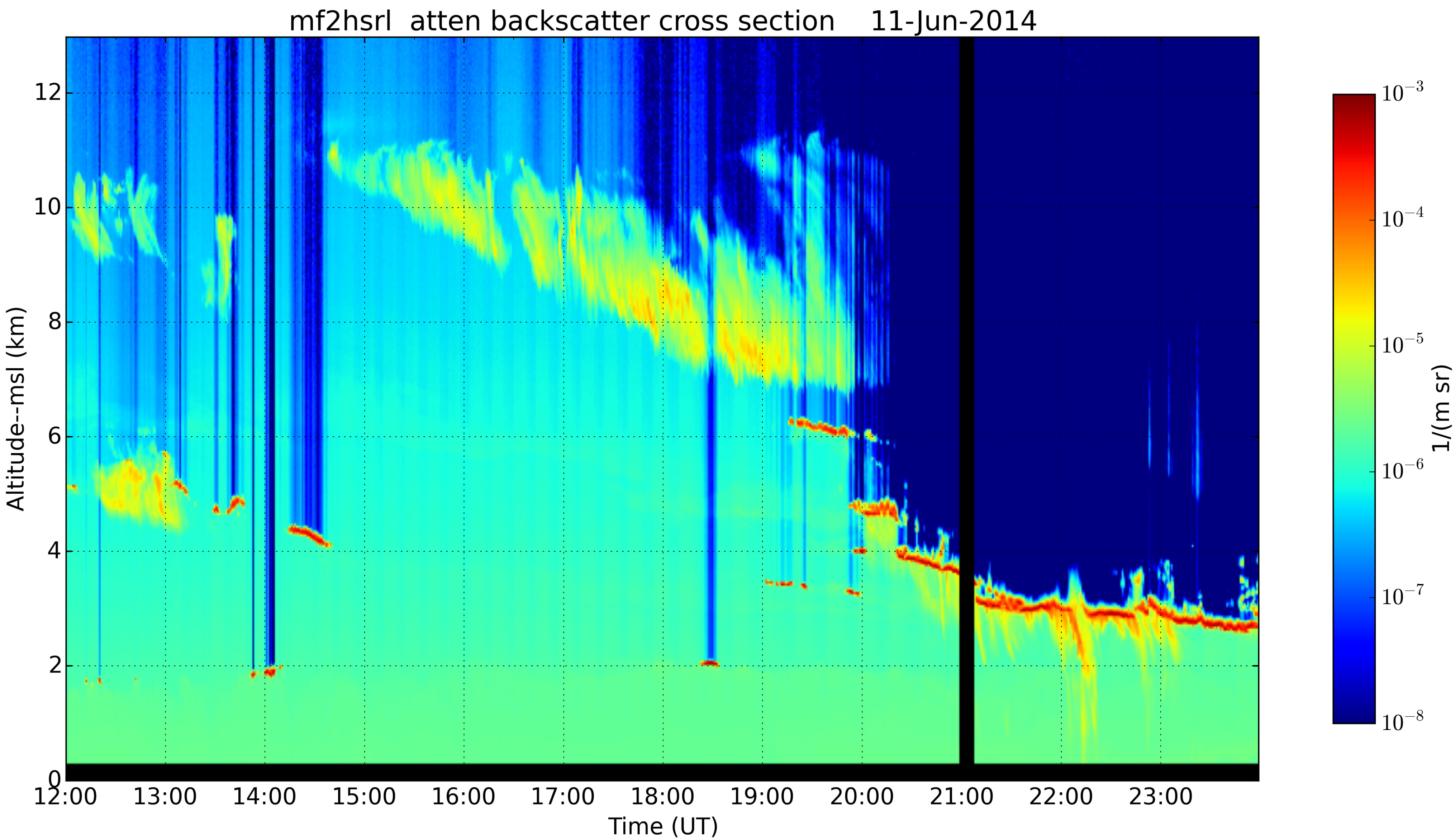
Backscatter ratio $= \dfrac{\beta'_{sa}(r)}{\beta'_m(r)} = \dfrac{p_a(r)}{p_m(r)} = \dfrac{\beta_a(r)}{\beta_m(r)} \cdot \dfrac{8\pi}{3} \dfrac{P(180,r)}{4\pi}$

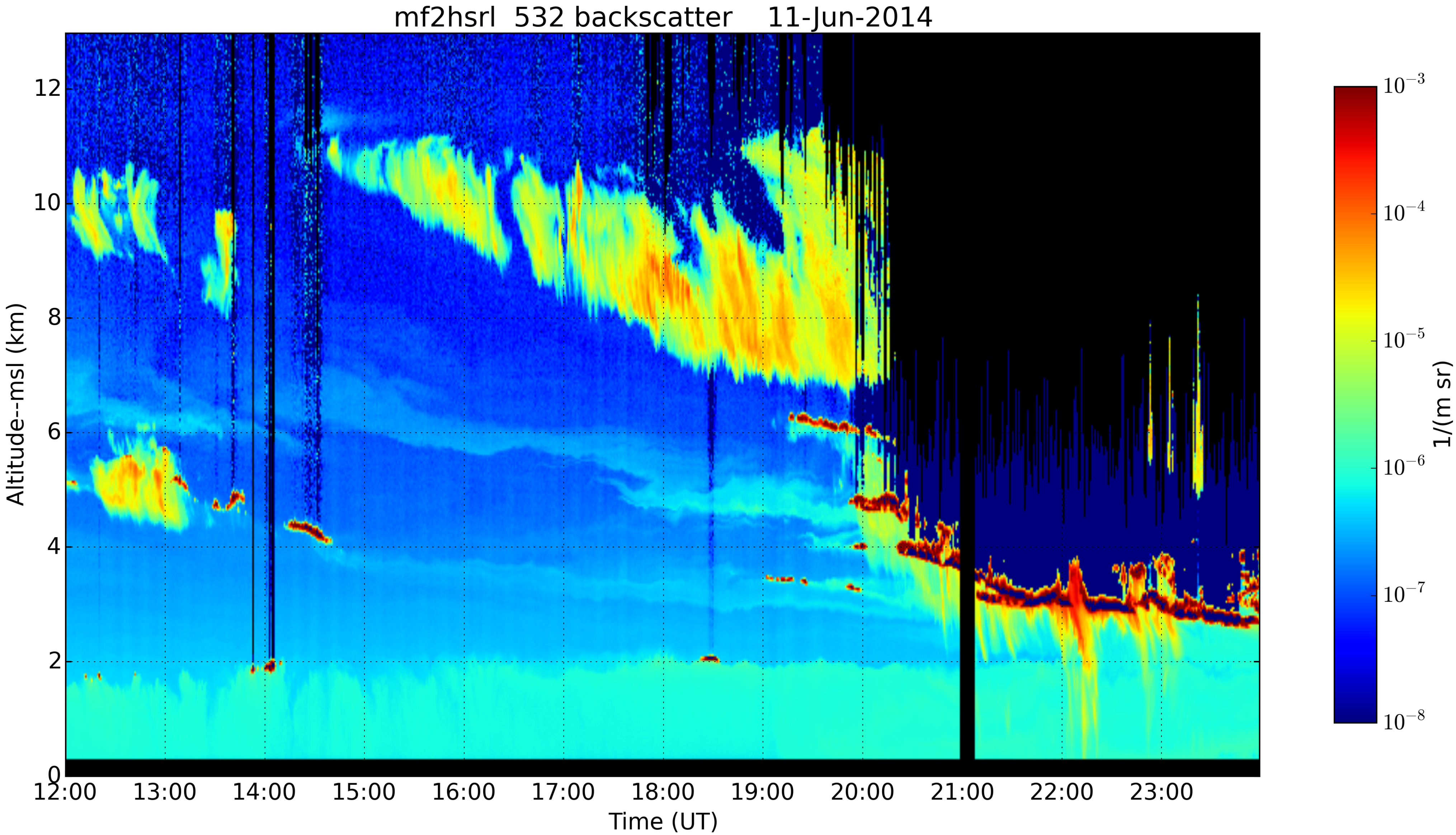

Aerosol
Bandwidth ~ 10 MHz
Freq ~ 6 x 10^14 Hz
Molecular
Bandwidth~3 GHz
Signal
Frequency offset (GHz)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
-5
-4
-3
-2
-1
0
1
2
3
4
5

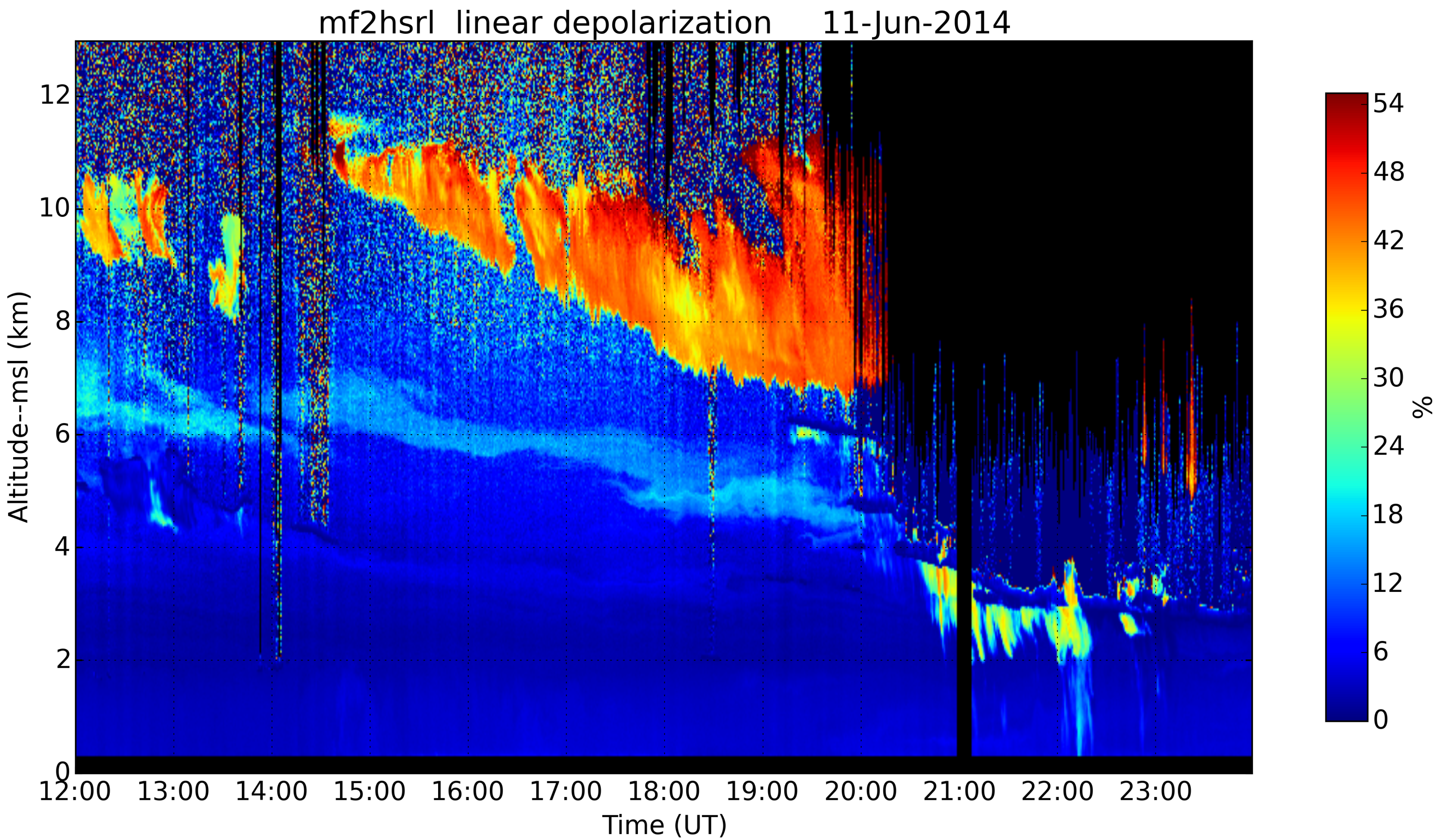

Signal
Frequency offset (GHz)
Beam splitter
Incoming light
Combined Channel Detector
Absorption Cell
Molecular Channel Detector
I2 cell transmission and Doppler broadened Atmospheric Backscatter
Relative transmission
Frequency (GHz)
Signal
Frequency offset (GHz)

mf2hsrl pileup+dark corrected counts 11-Jun-2014 12:50 --. 13:00



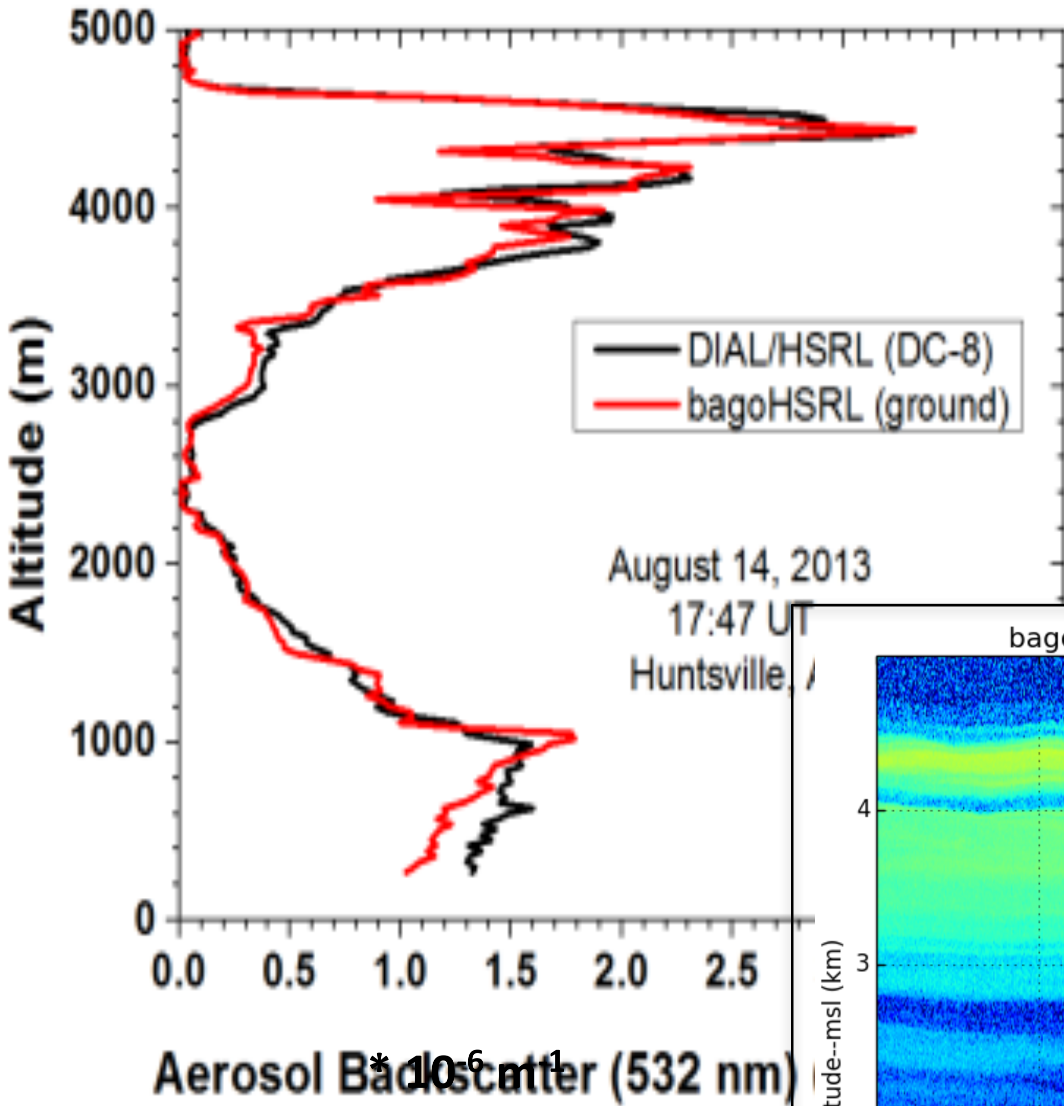

mf2hsrl atten backscatter cross section 11-Jun-2014
Altitude--msl (km)
0
2
4
6
8
10
12
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time (UT)
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
1/(m sr)


mf2hsrl 532 backscatter 11-Jun-2014
Altitude--msl (km)
0
2
4
6
8
10
12
Time (UT)
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
1/(m sr)
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}

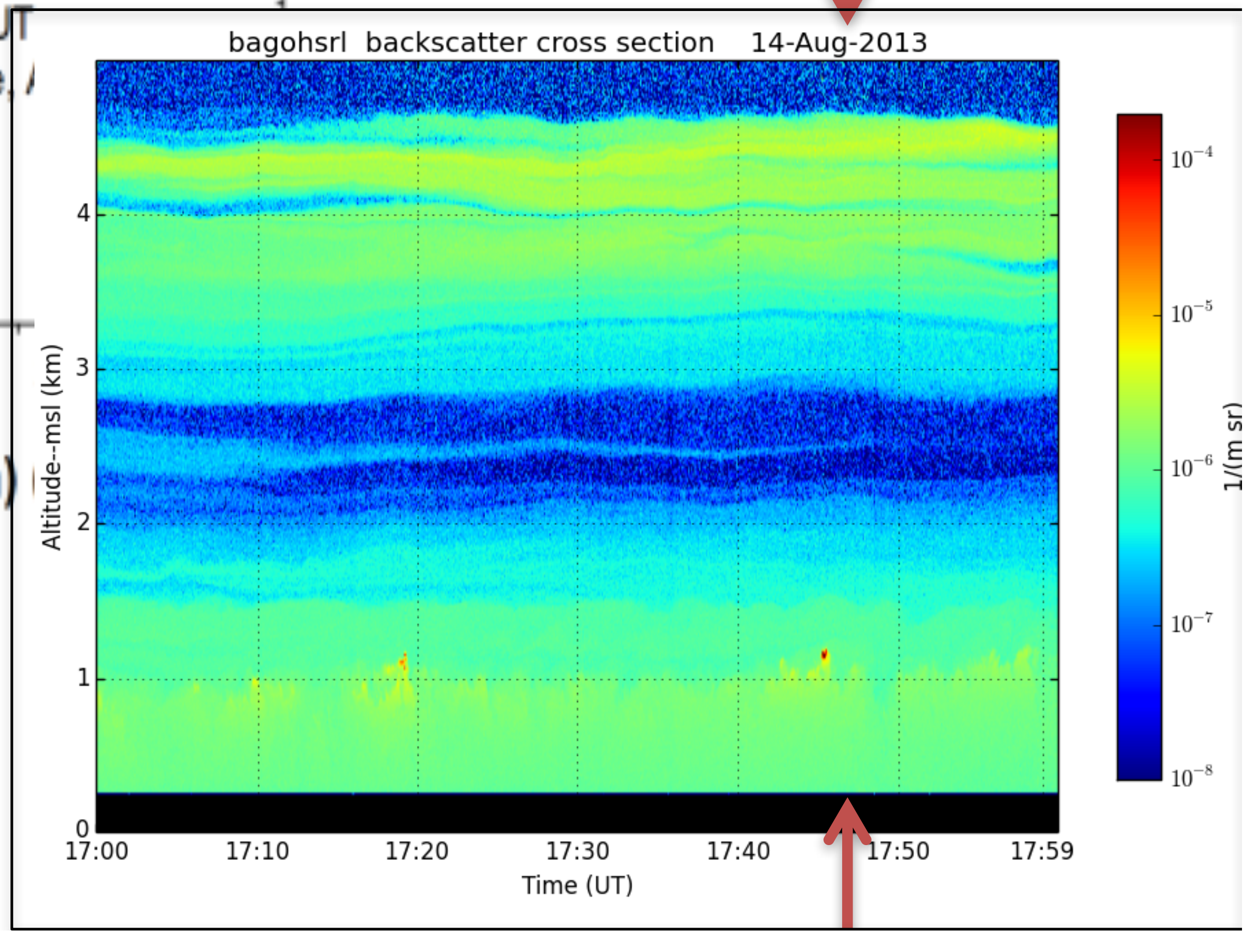

mf2hsrl linear depolarization 11-Jun-2014
Altitude--msl (km)
0
2
4
6
8
10
12
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time (UT)
0
6
12
18
24
30
36
42
48
54
%

Backscatter cross section:
UW HSRL (red)
Langley HSRL (black)

August 14, 2013 17:47 UT
Huntsville, Alabama

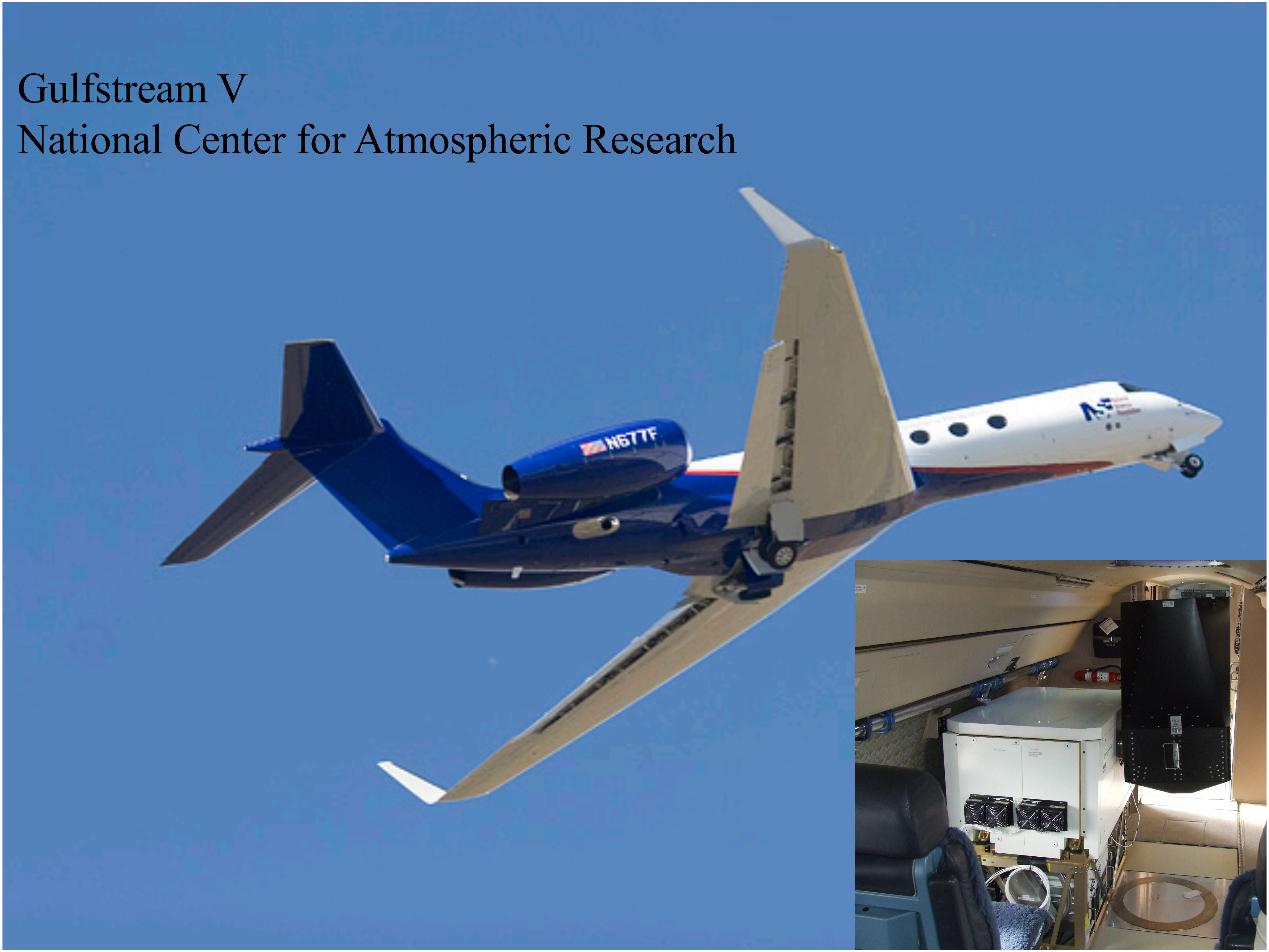


17:47 UT



Transmitted power	250 mW
Wavelength	532 nm
Pulse repetition rate	4 kHz
Common transmit-receive telescope	40 cm diameter
Safe for direct viewing of output beam	
Receiver field-of-view	100 micro-radian
Sky noise filter bandwidth	8 GHz
Range resolution	7.5 m

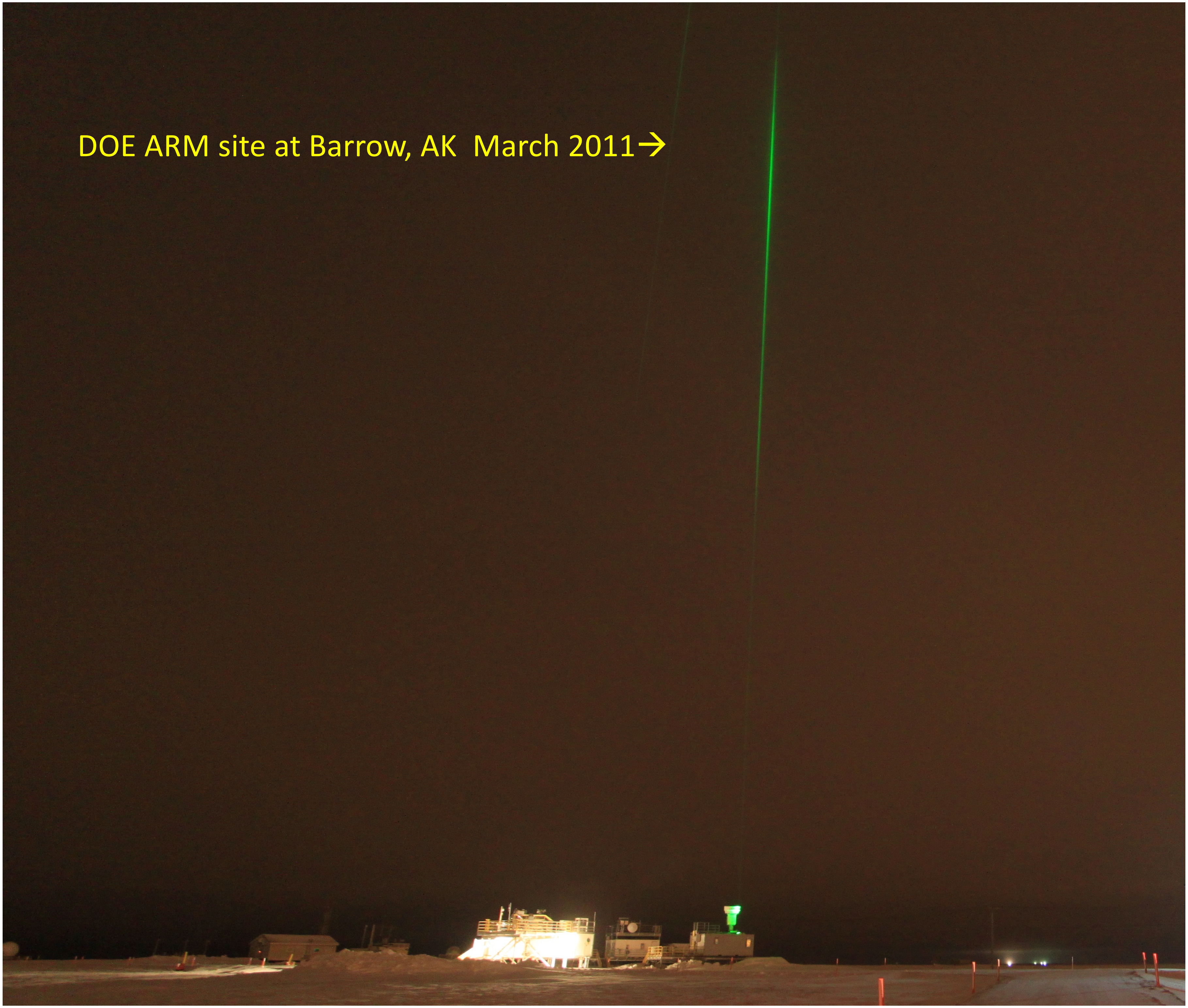
Mt Werner
Steamboat Springs Colorado


Gulfstream V
National Center for Atmospheric Research
N677F

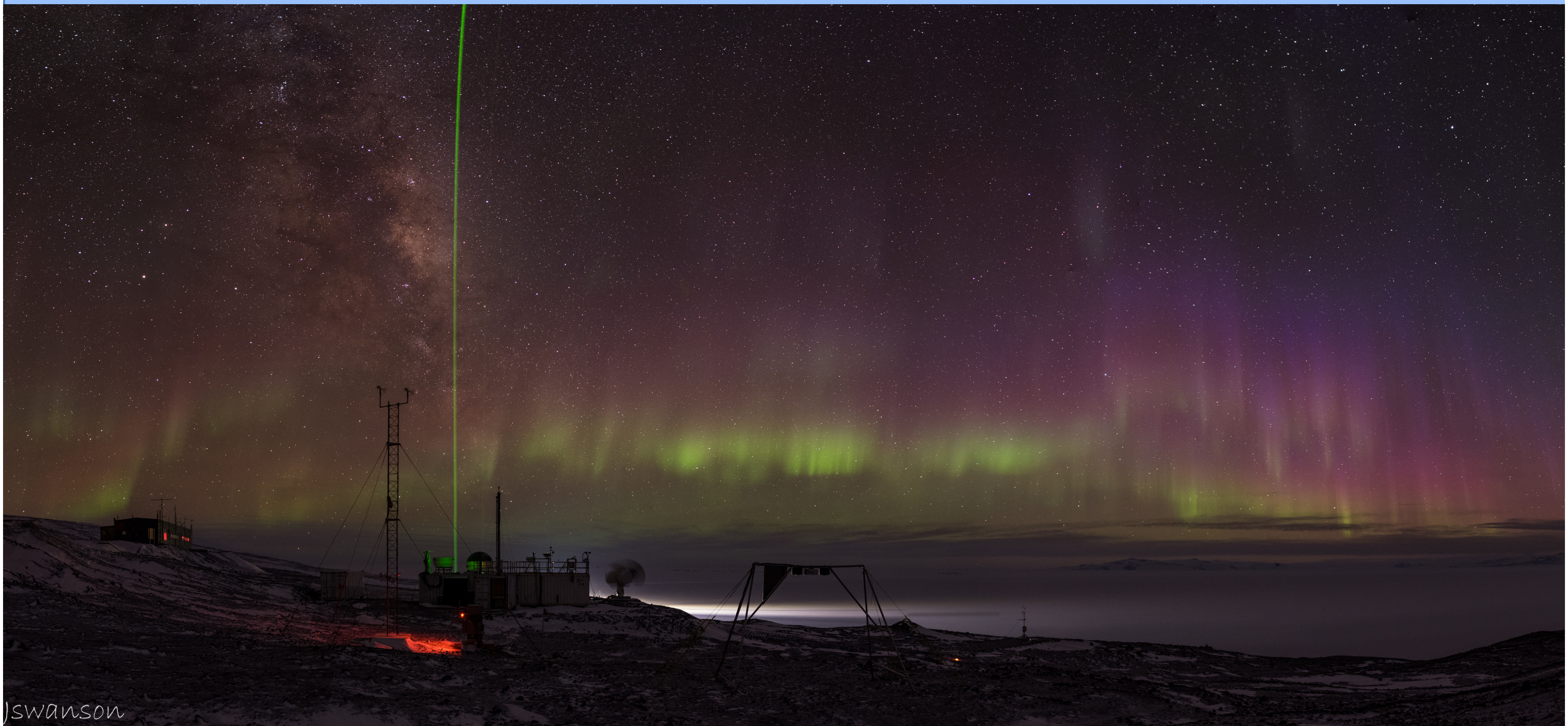

Eureka Weather Station
Ellesmere Island, Nunavut


WARNING
STAY OFF THE ROOF
DURING THUNDERSTORMS
Singapore

DOE MAGIC IOP – 6-months on the Horizon Spirit


DOE ARM site at Barrow, AK March 2011→

DOE AWARE Campaign, McMurdo Antarctica

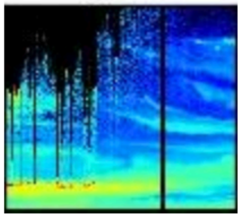


Previous

Seoul, Korea (AHSRL: Mar 2016 - present)
AHSRL-IR Backscatt Full Month View

AHSRL–IR Backscatt | May | 2016 | Update

Return to Data Portal

1-May-2016 AM

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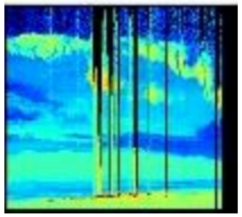
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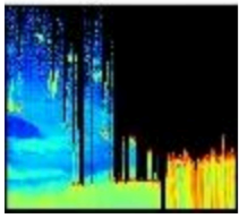
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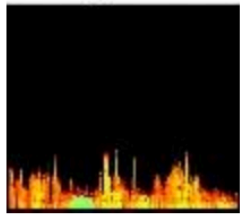
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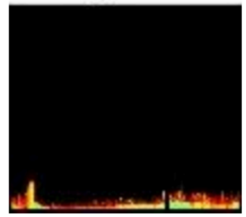
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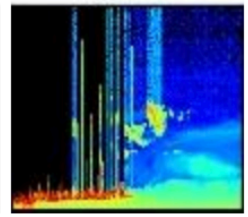
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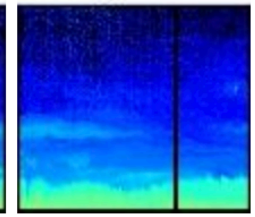
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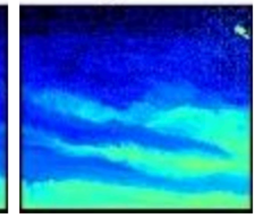
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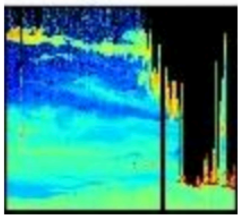
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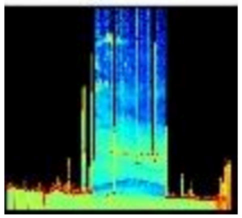
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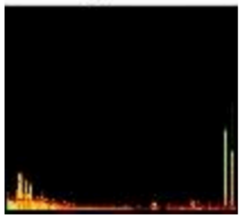
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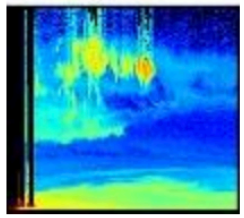
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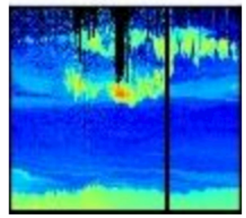
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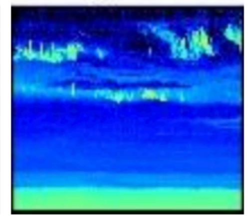
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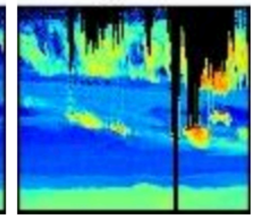
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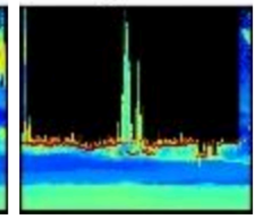
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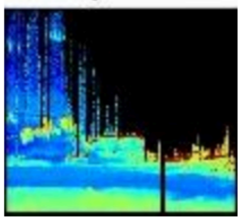
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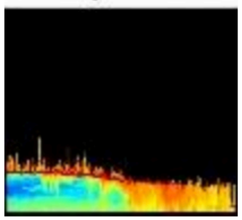
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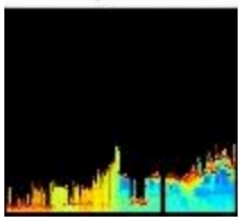
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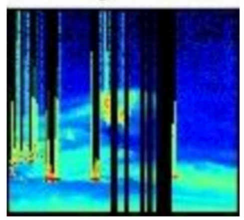
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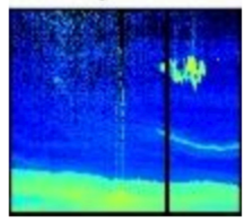
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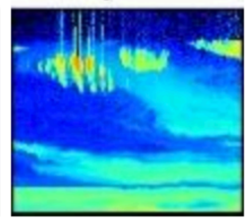
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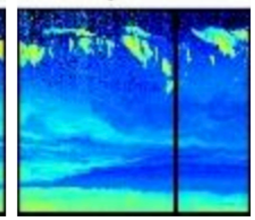
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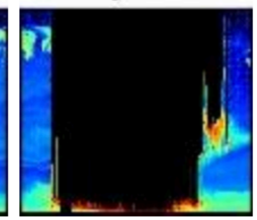
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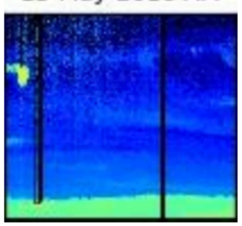
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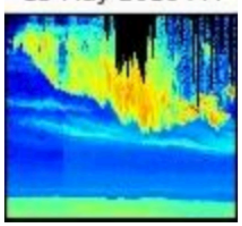
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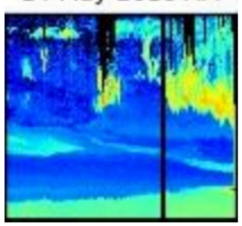
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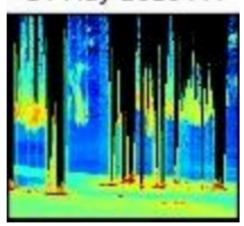
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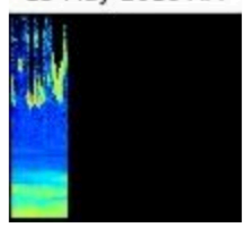
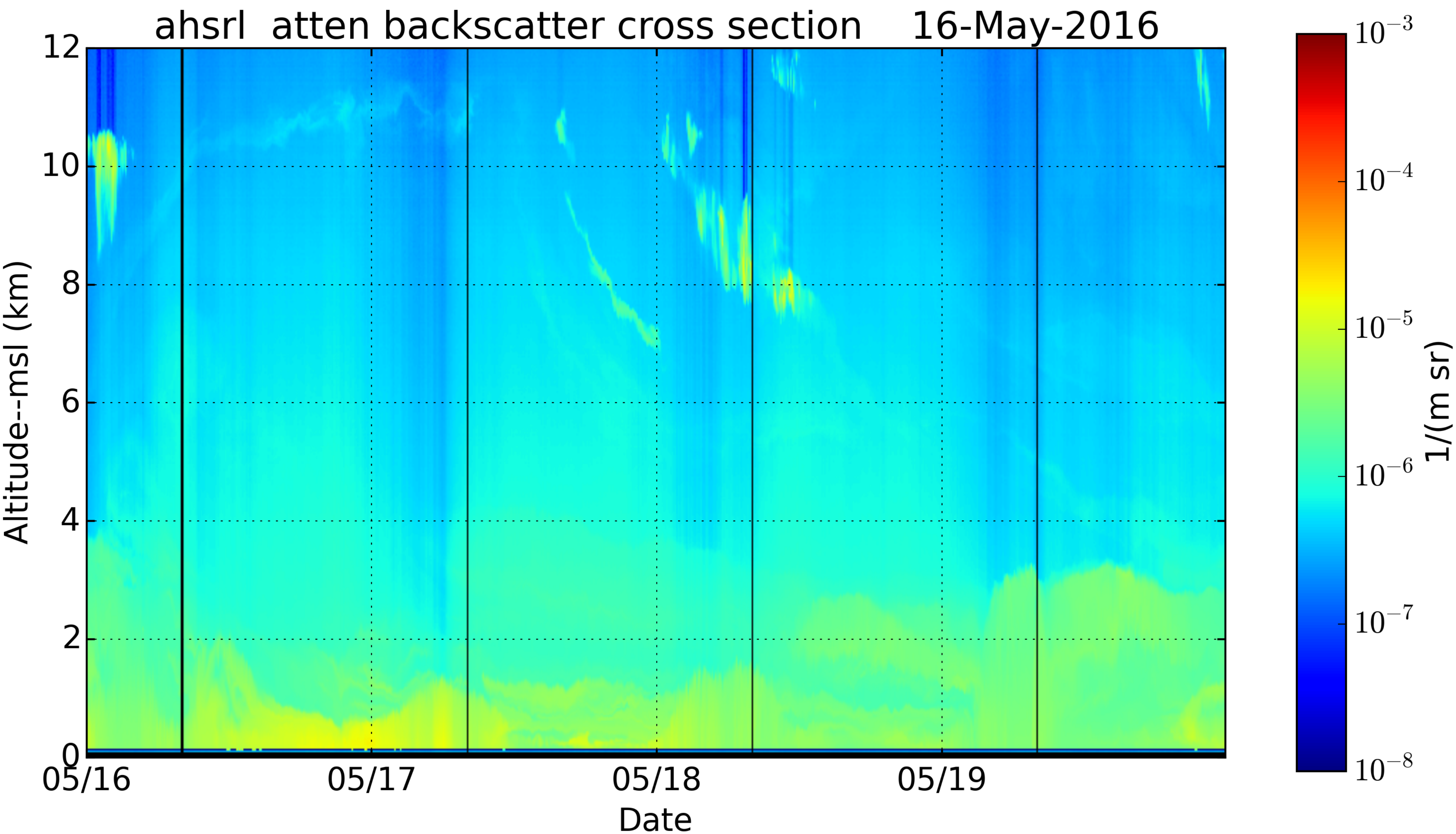
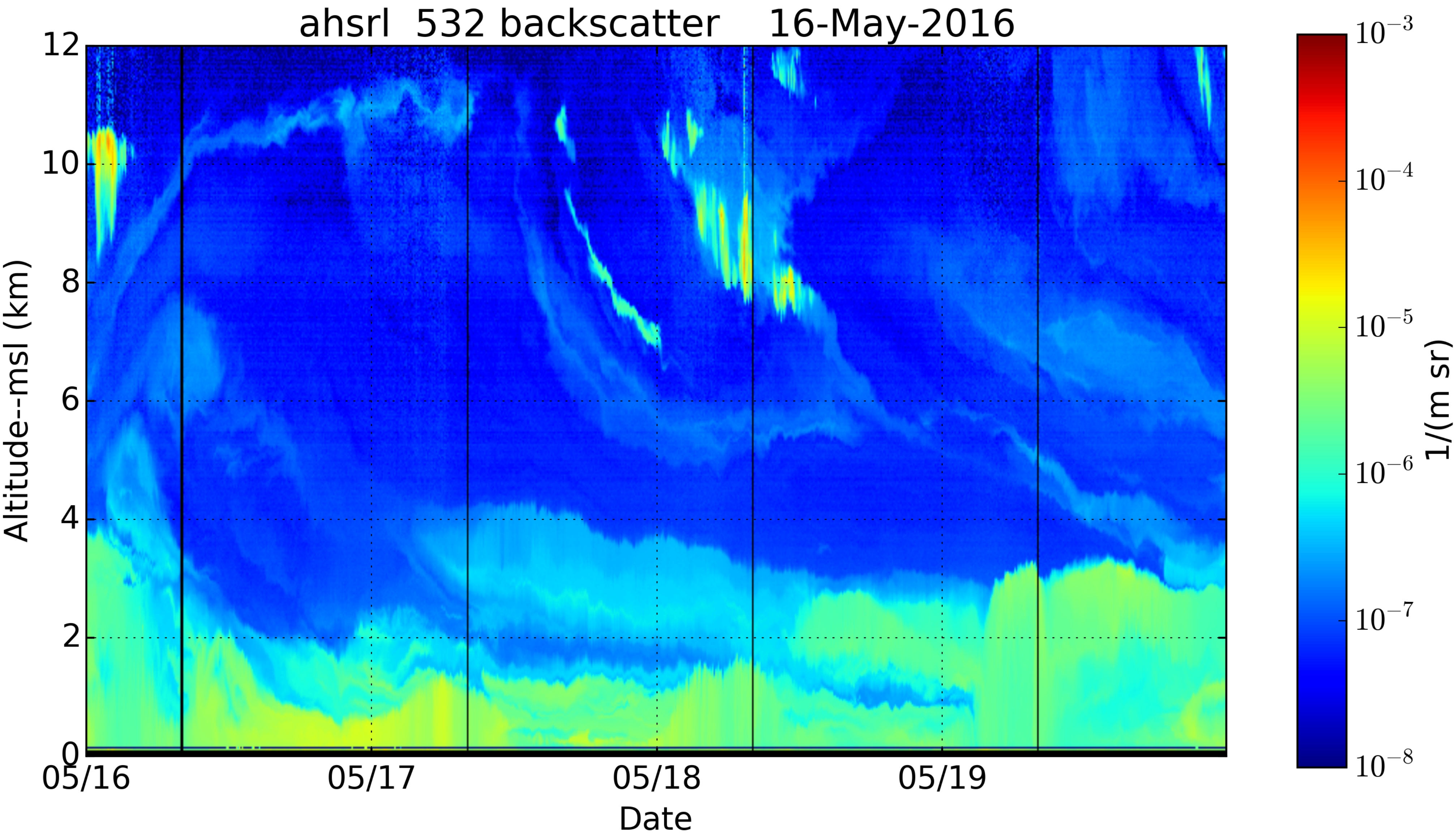
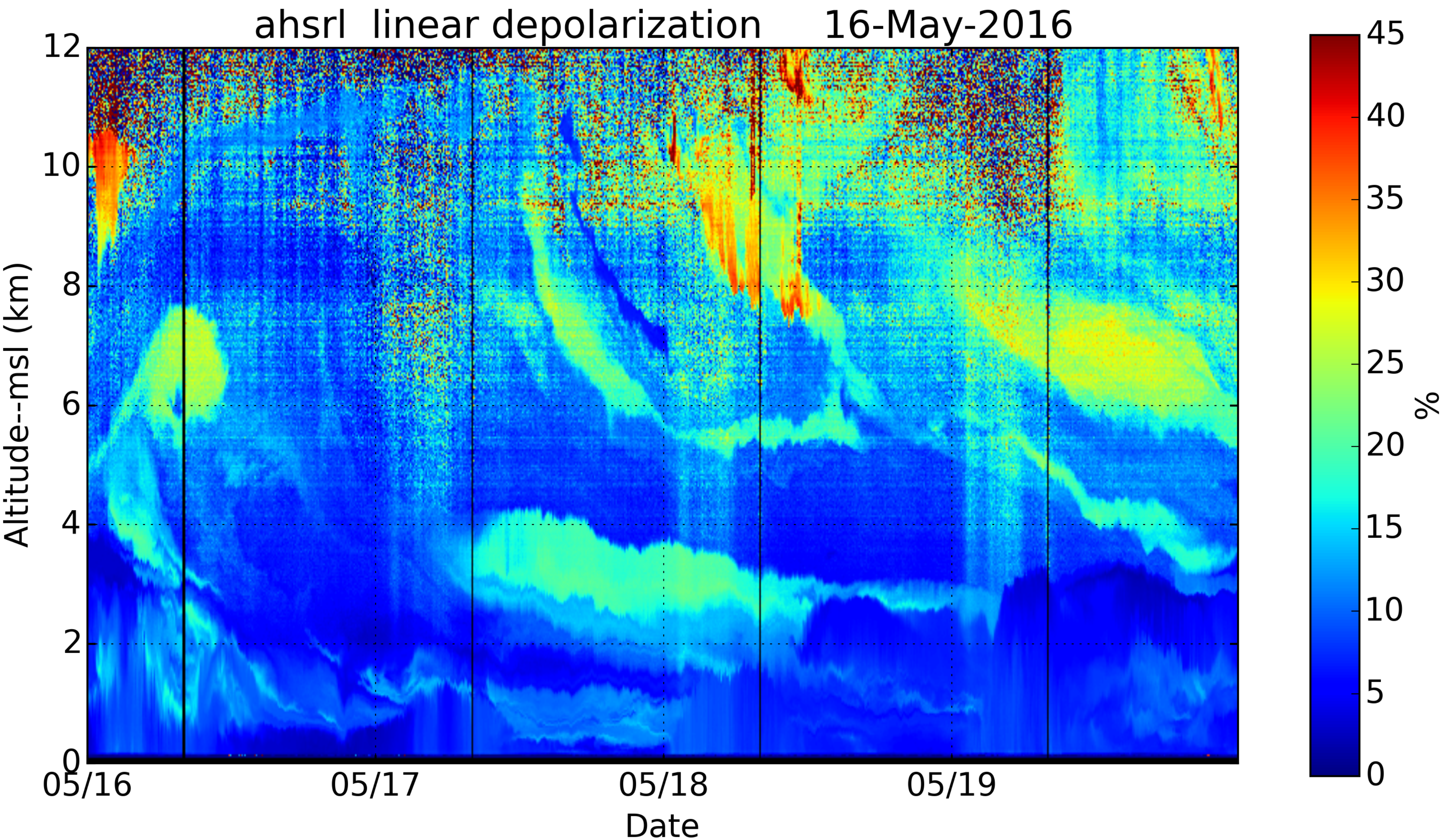


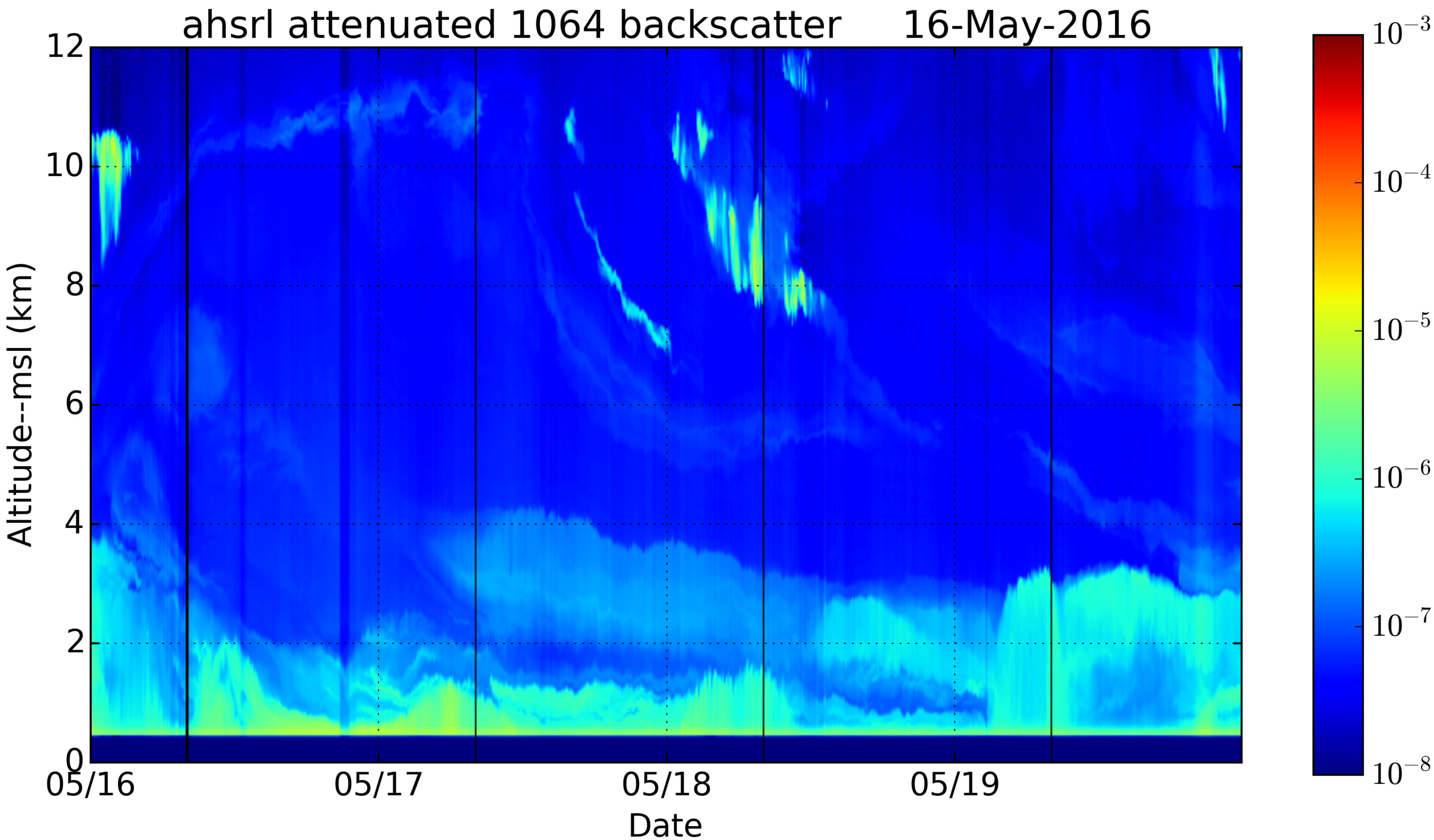
KORUS –AQ   Seoul National University, Seoul Korea




ahsrl 532 backscatter 16-May-2016
Altitude--msl (km)
12
10
8
6
4
2
0
05/16
05/17
05/18
05/19
Date
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
1/(m sr)



ahsrl linear depolarization 16-May-2016
Altitude--msl (km)
0
2
4
6
8
10
12
05/16
05/17
05/18
05/19
Date
%
0
5
10
15
20
25
30
35
40
45



ahsrl attenuated 1064 backscatter 16-May-2016
Altitude--msl (km)
0
2
4
6
8
10
12
05/16
05/17
05/18
05/19
Date
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}

Ratio of 1064 to 532 backscatter cross-sections

Known from sounding

$$\frac{(\beta_m+\beta_a)_{1064}}{(\beta_m+\beta_a)_{532}} = \frac{S_{1064}}{S_{532}} \cdot \frac{G_{532}}{G_{1064}} \cdot exp(\frac{30}{16} \cdot \tau_m - 2 \cdot \tau_a \cdot (1 - 2^{-A}))$$

Ratio of total backscatter cross-sections

Measured signals

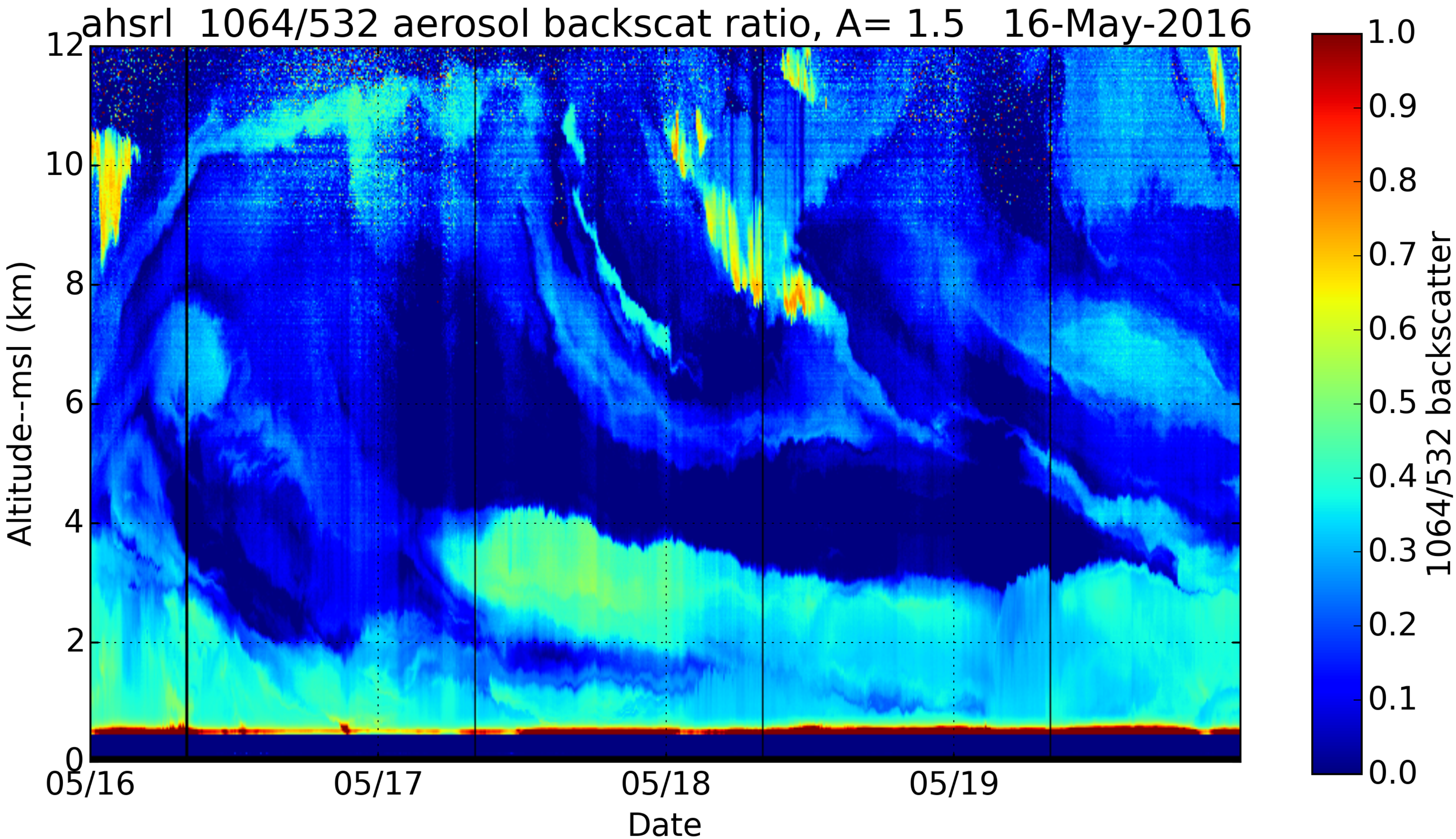
Channel gains

Differential attenuation 1064nm /532nm

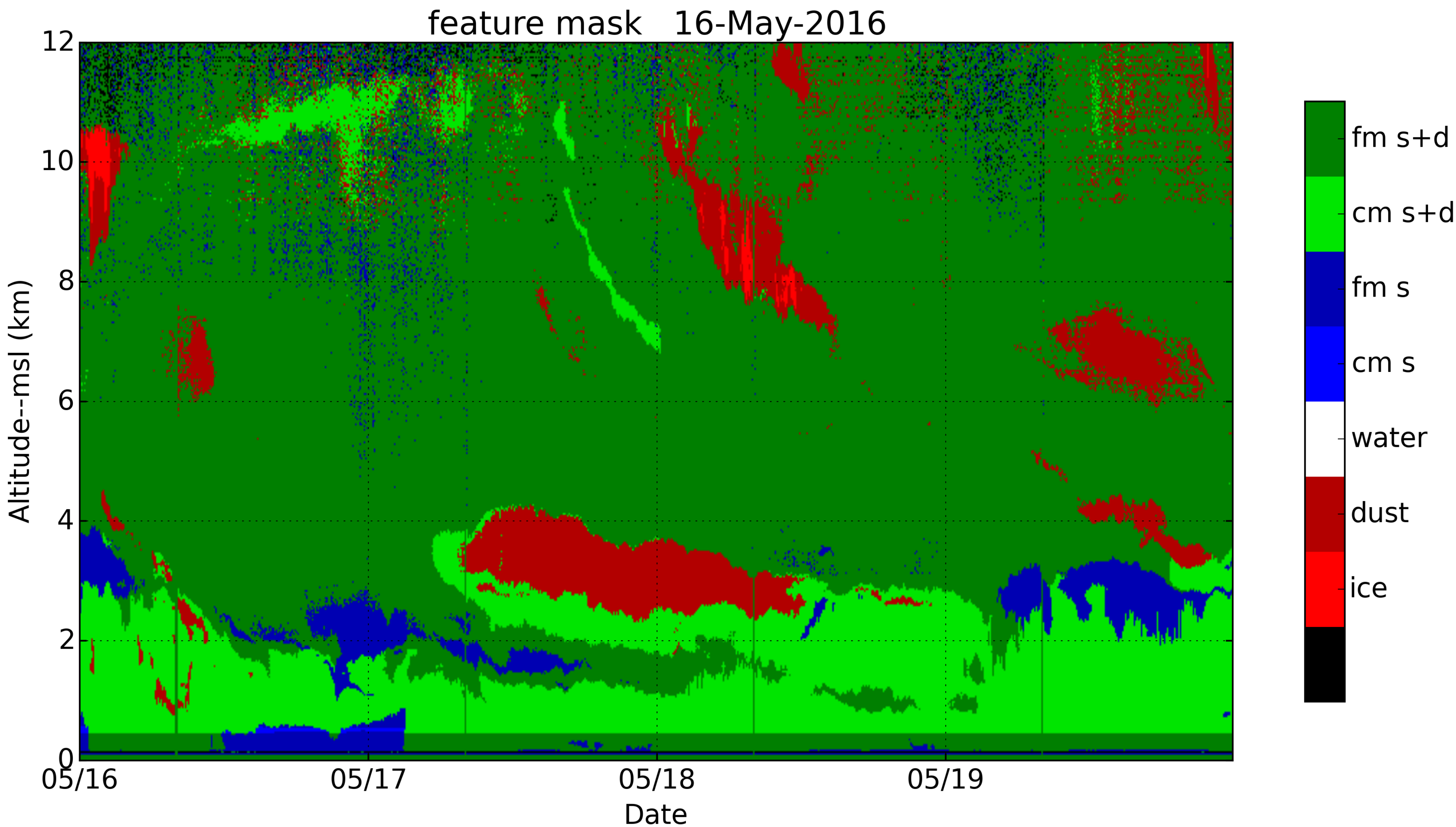
532nm Molecular Optical depth from sounding

HSRL measured 532 nm optical depth

Angstromc



ahsrl 1064/532 aerosol backscat ratio, A= 1.5 16-May-2016
Altitude--msl (km)
0
2
4
6
8
10
12
05/16
05/17
05/18
05/19
Date
1064/532 backscatter
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0



feature mask 16-May-2016
Altitude--msl (km)
0
2
4
6
8
10
12
05/16
05/17
05/18
05/19
Date
fm s+d
cm s+d
fm s
cm s
water
dust
ice

The extinction cross section, β_e , can be derived from the molecular return by taking the logarithm and then differentiating with respect to range, r:

$$S_m(r) \sim \eta(r) \cdot \frac{1}{r^2} \cdot \frac{3}{8\pi} \cdot \beta_m(r) \cdot e^{-2\int_0^r \beta_e(r)dr}$$

Taking the logarithm and differentiating with respect to range Provides the extinction cross section in terms of S_m and β_m :

$$\beta_e(r) = \frac{1}{2} \cdot \frac{d}{dr}[log(\frac{\eta(r) \cdot \beta_m(r)}{r^2 \cdot S_m(r)})]$$

Unfortunately, the geometric correction, $\eta(r)$, does not cancel out:

$$\beta_e(r) = \frac{1}{2} \cdot \frac{d}{dr}[log(\frac{\eta(r) \cdot \beta_m(r)}{r^2 \cdot S_m(r)})]$$

Expanding this equation for extinction cross section yields an expression that can be used to examine the effects of uncertainties in the variables:

$$\beta_e(r) = \frac{1}{2\eta}\frac{d\eta}{dr} + \frac{1}{2\beta_m}\frac{d\beta_m}{dr} - \frac{1}{r} + \frac{1}{S_m}\frac{dS_m}{dr}$$

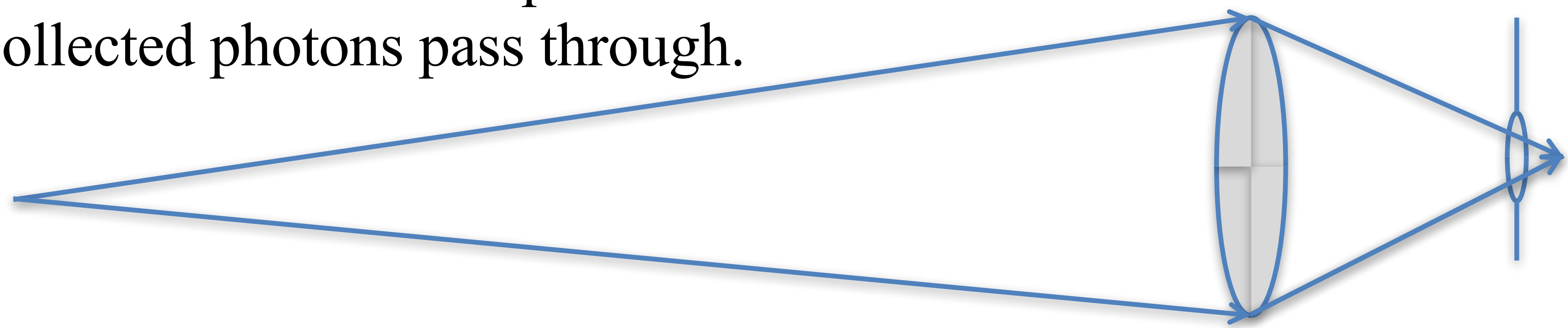
Geometric correction

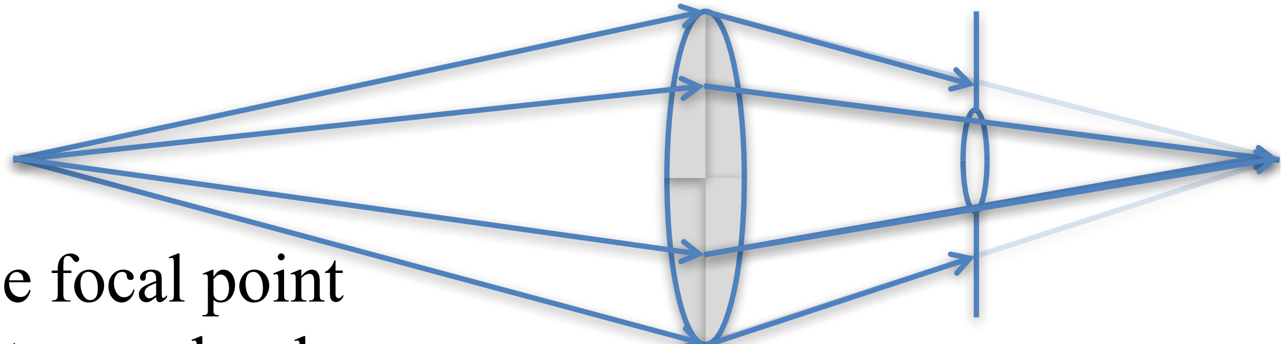
Molecular scattering cross section

The measured molecular signal

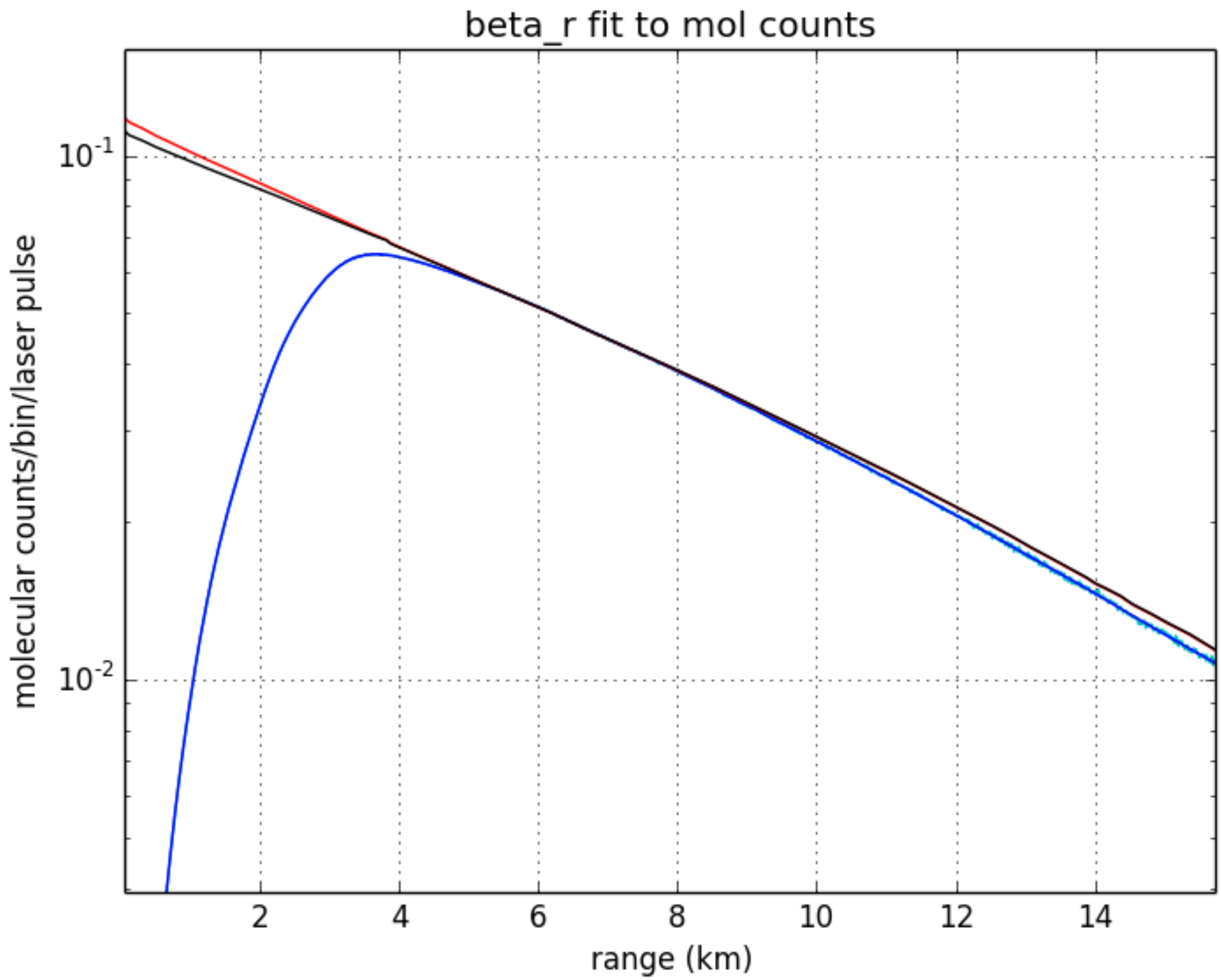
The Geometry Correction, g(r)

At long ranges the telescope focal point is close to the field stop and all of the collected photons pass through.





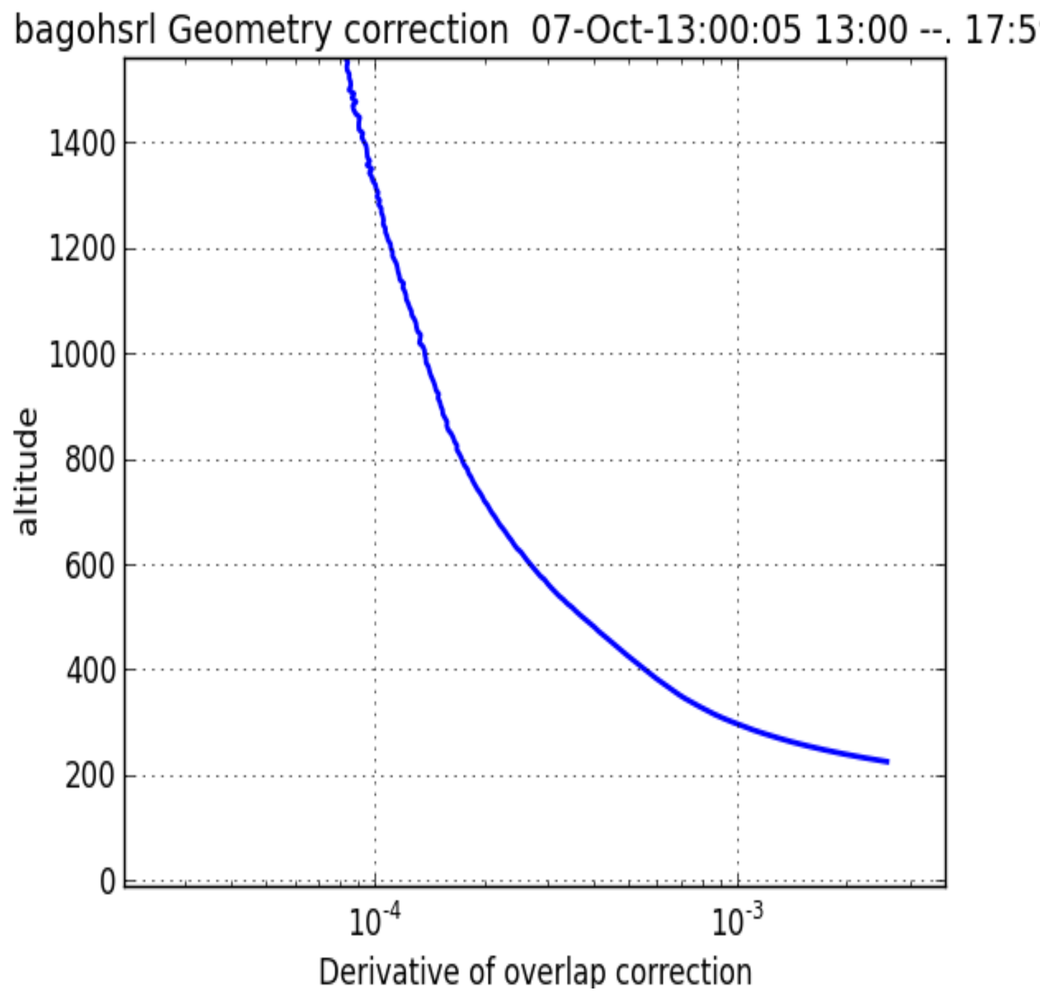
At close range the telescope focal point Is farther behind the field stop and only those photons hitting near the center of the objective pass through the field stop.



beta_r fit to mol counts
molecular counts/bin/laser pulse
range (km)
10^-1
10^-2
2
4
6
8
10
12
14

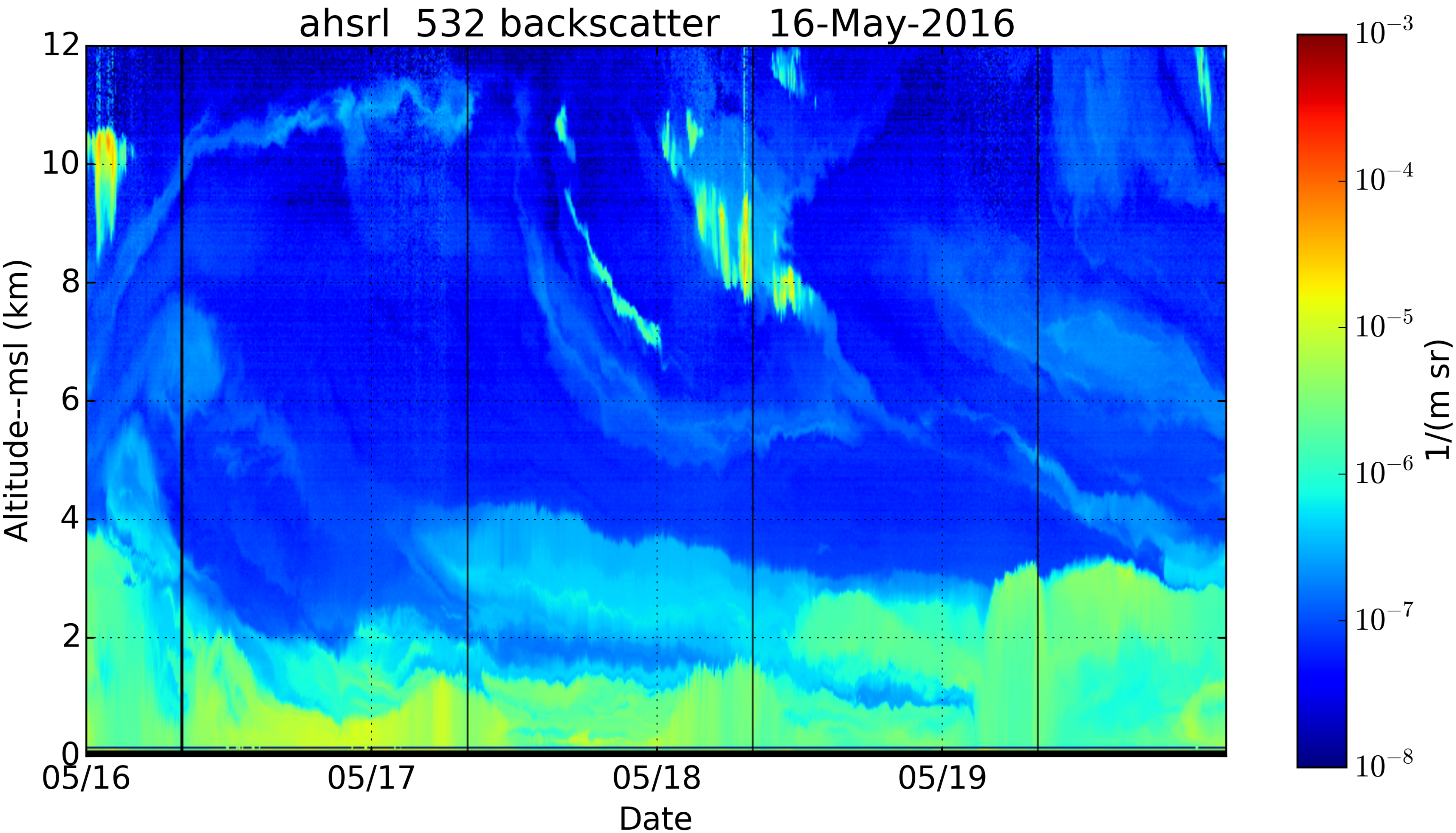
Geometric correction

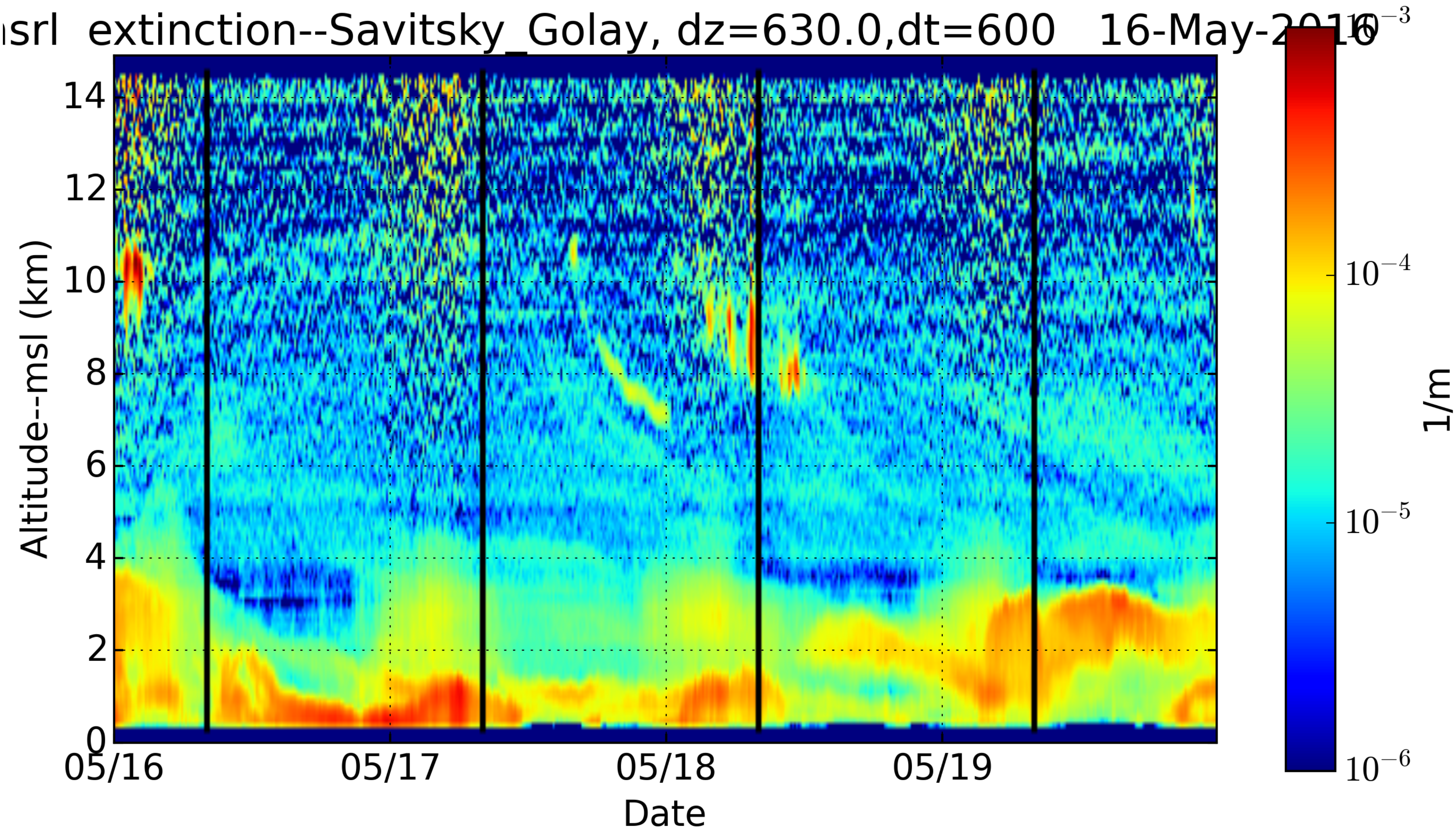
$$\beta_e(r) = \frac{1}{2\eta}\frac{d\eta}{dr}$$



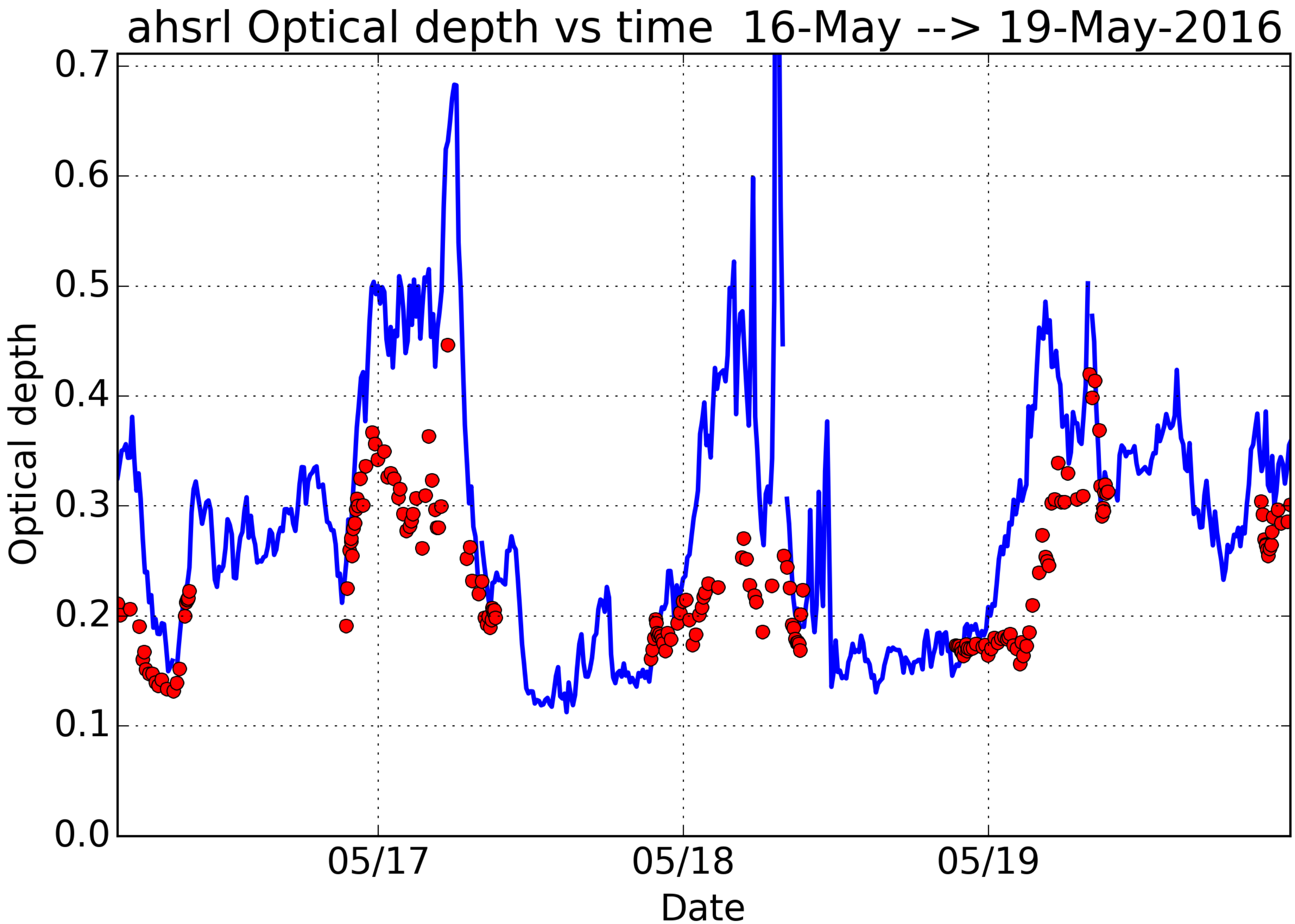
At 300m, β_e correction ~ 10^{-3}, for 10% at 10^{-5} need 0.1% measurement

At 1.3km, β_e correction ~ 10^{-4}, for 10% at 10^{-5} need 1% measurement

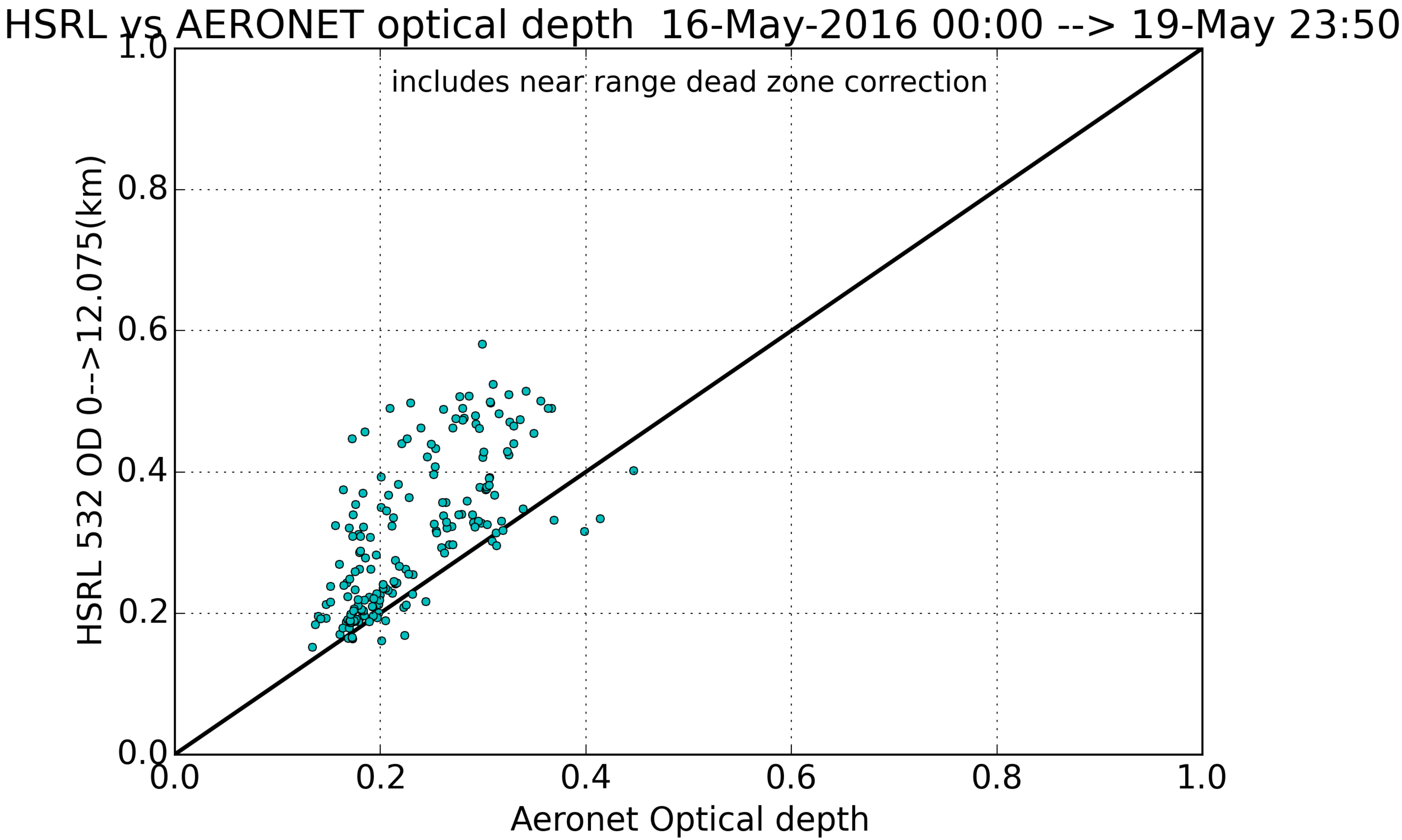

ahsrl 532 backscatter 16-May-2016
Altitude--msl (km)
0
2
4
6
8
10
12
05/16
05/17
05/18
05/19
Date
1/(m sr)
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}



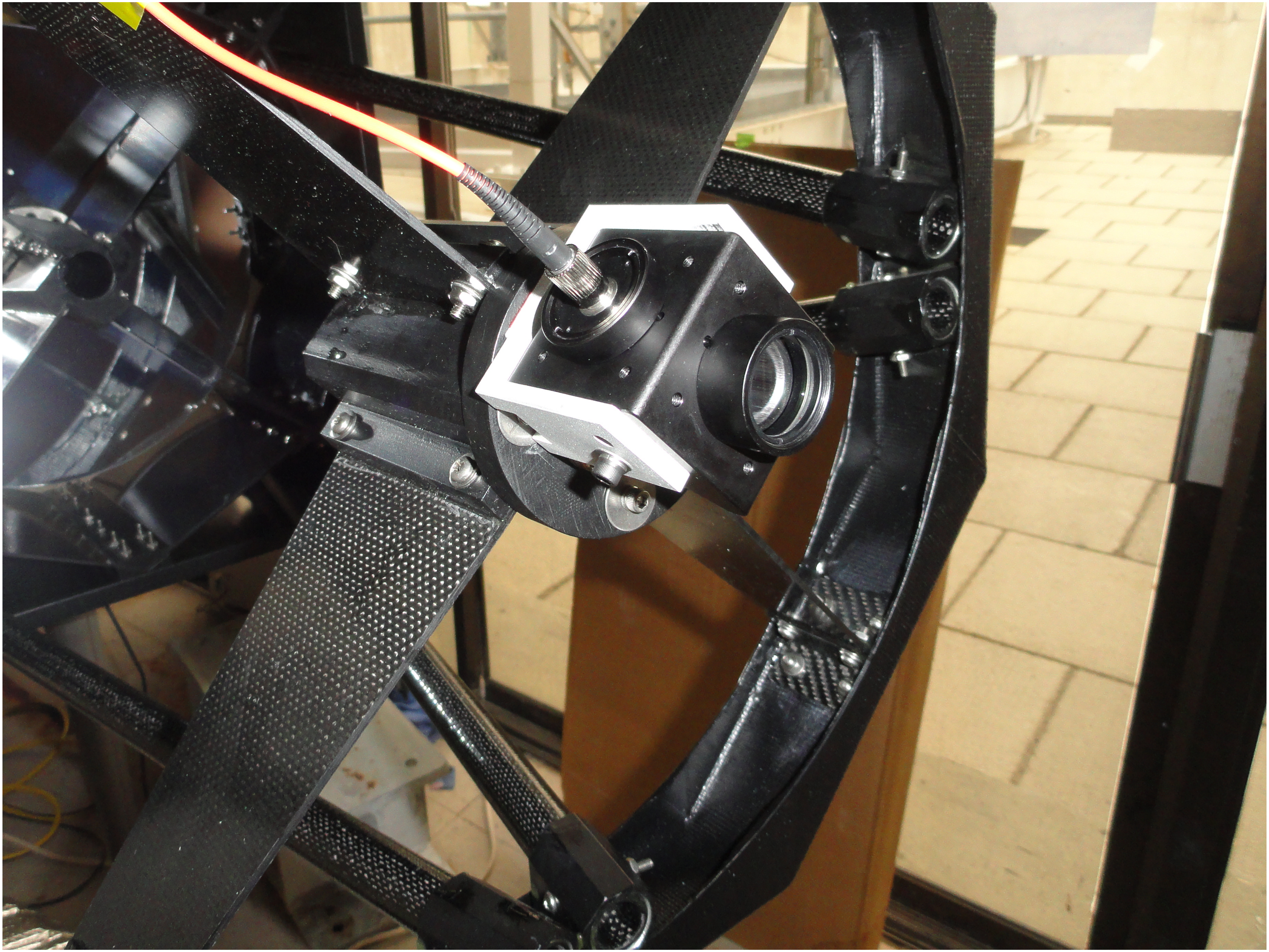
Variations in overlap function produce artifacts in aerosol extinction

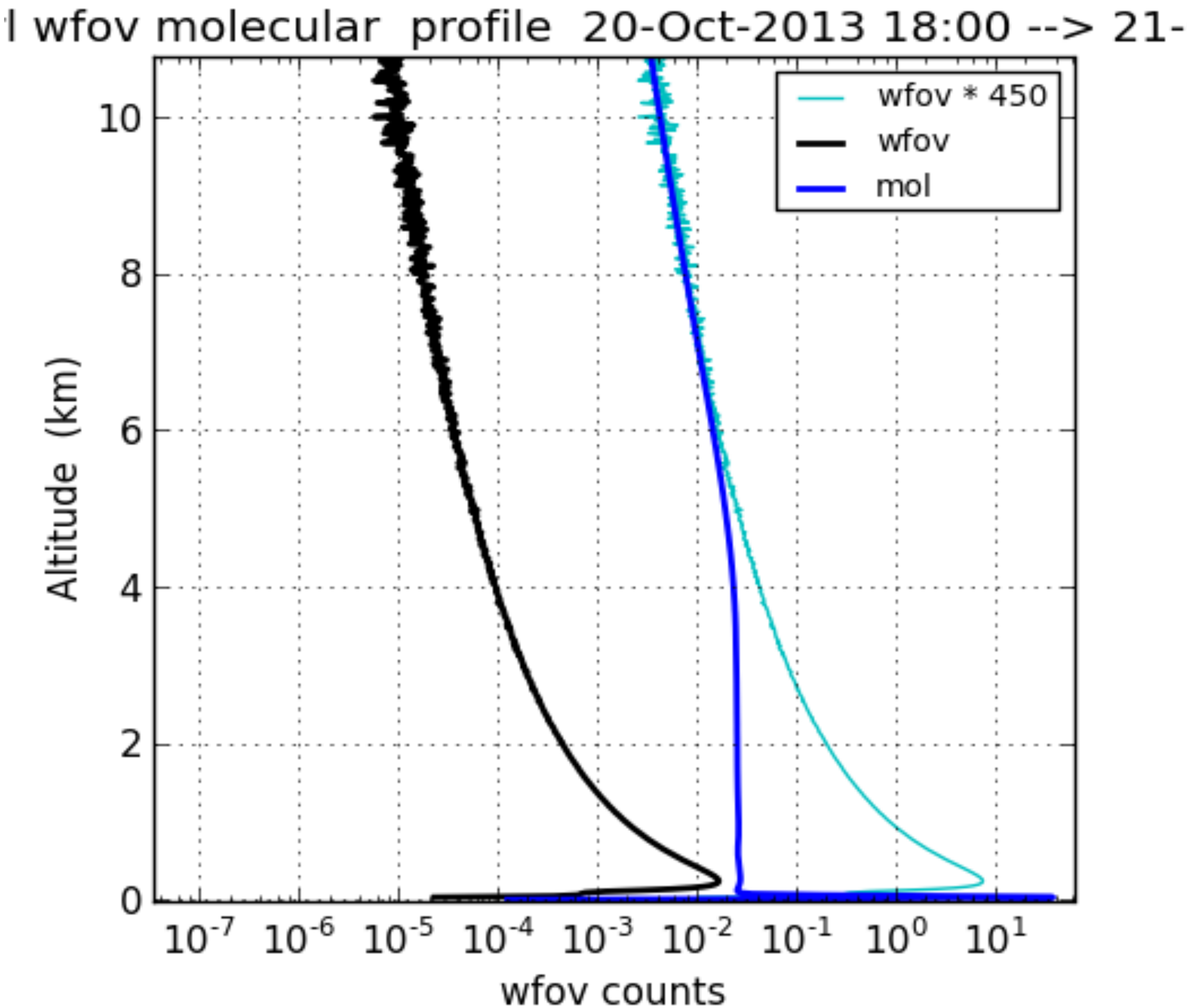


ahsrl Optical depth vs time 16-May --> 19-May-2016
Optical depth
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
05/17
05/18
05/19
Date

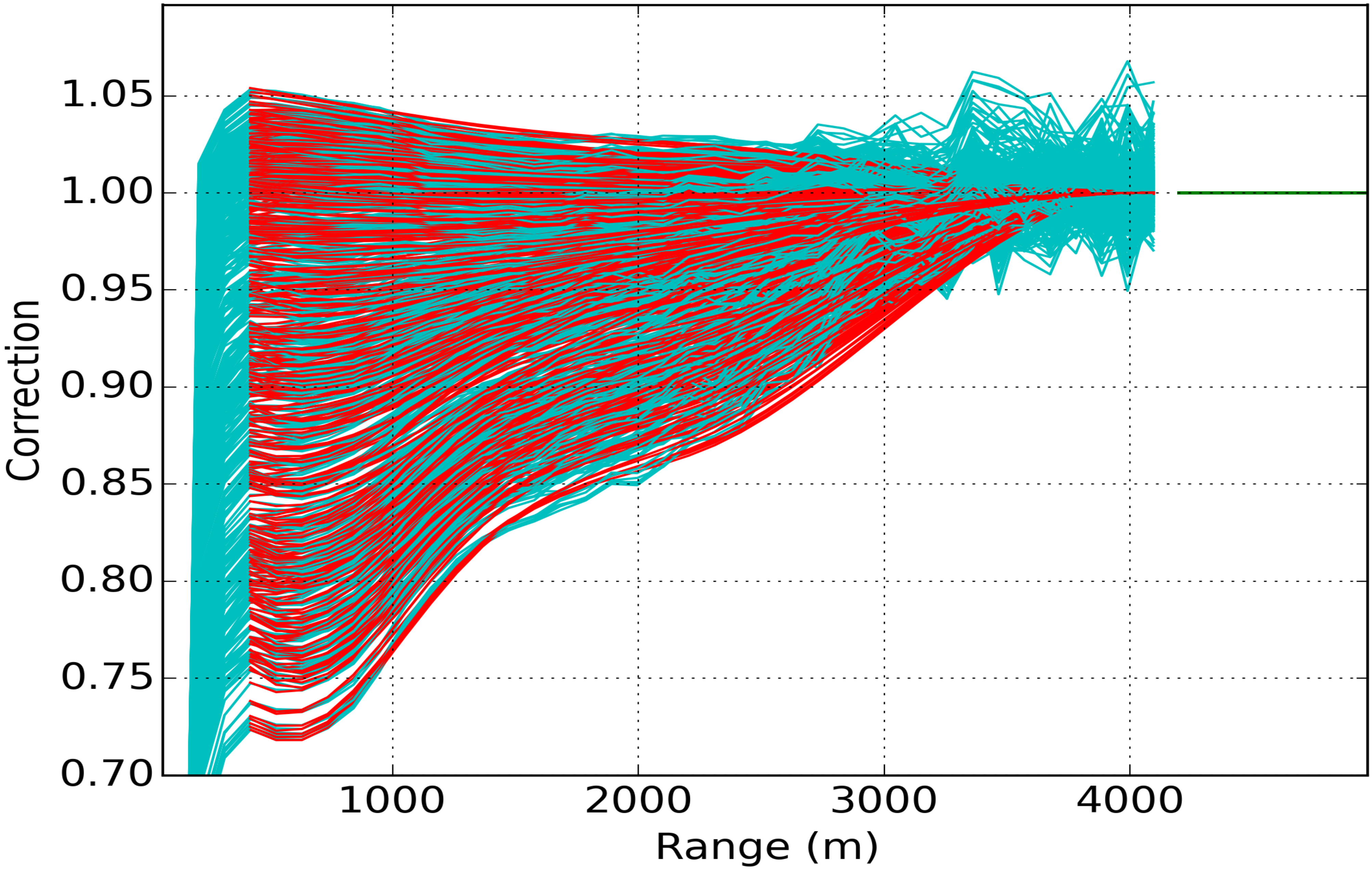


HSRL vs AERONET optical depth 16-May-2016 00:00 --> 19-May 23:50
includes near range dead zone correction
HSRL 532 OD 0-->12.075(km)
Aeronet Optical depth
0.0
0.2
0.4
0.6
0.8
1.0

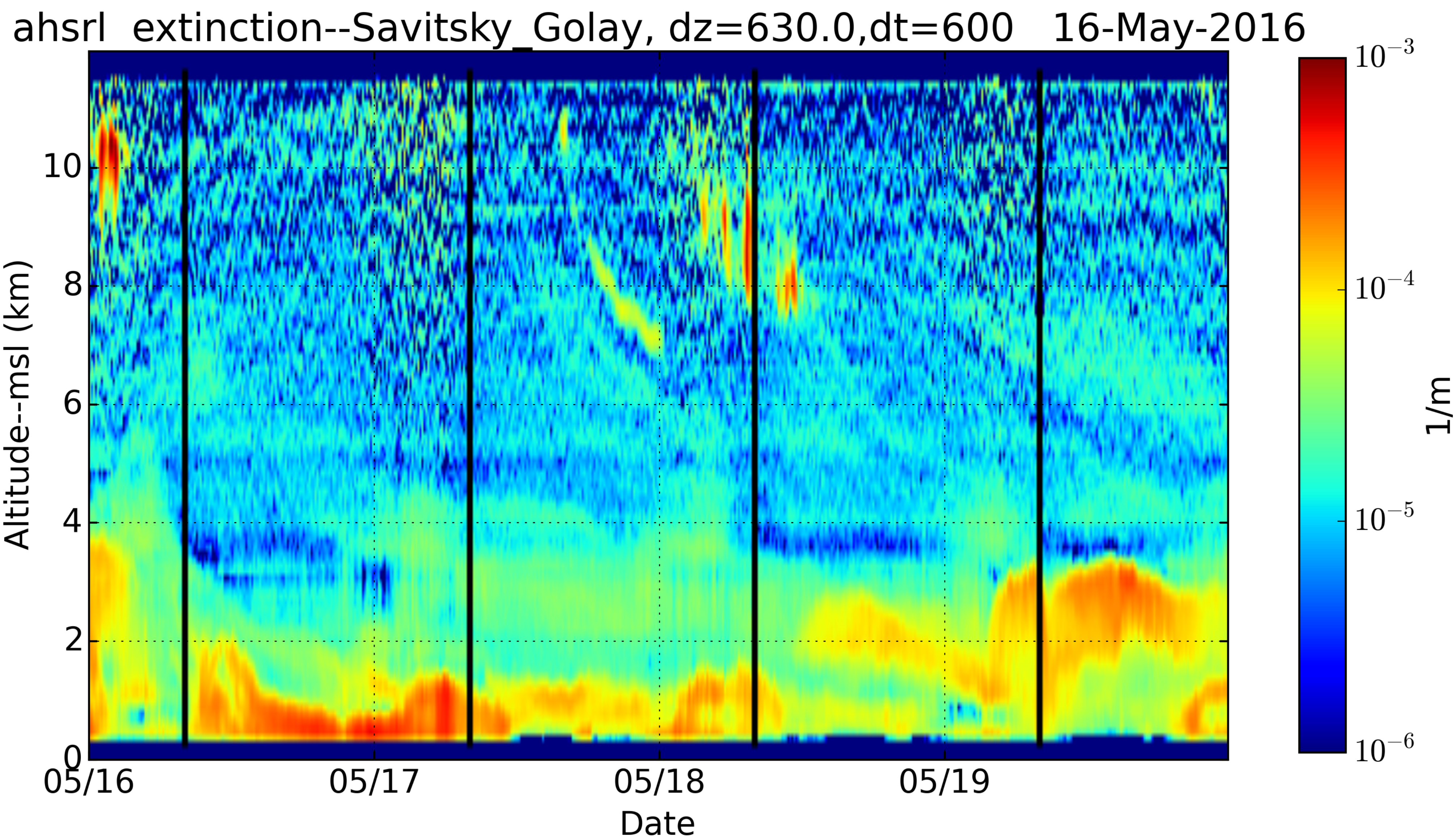


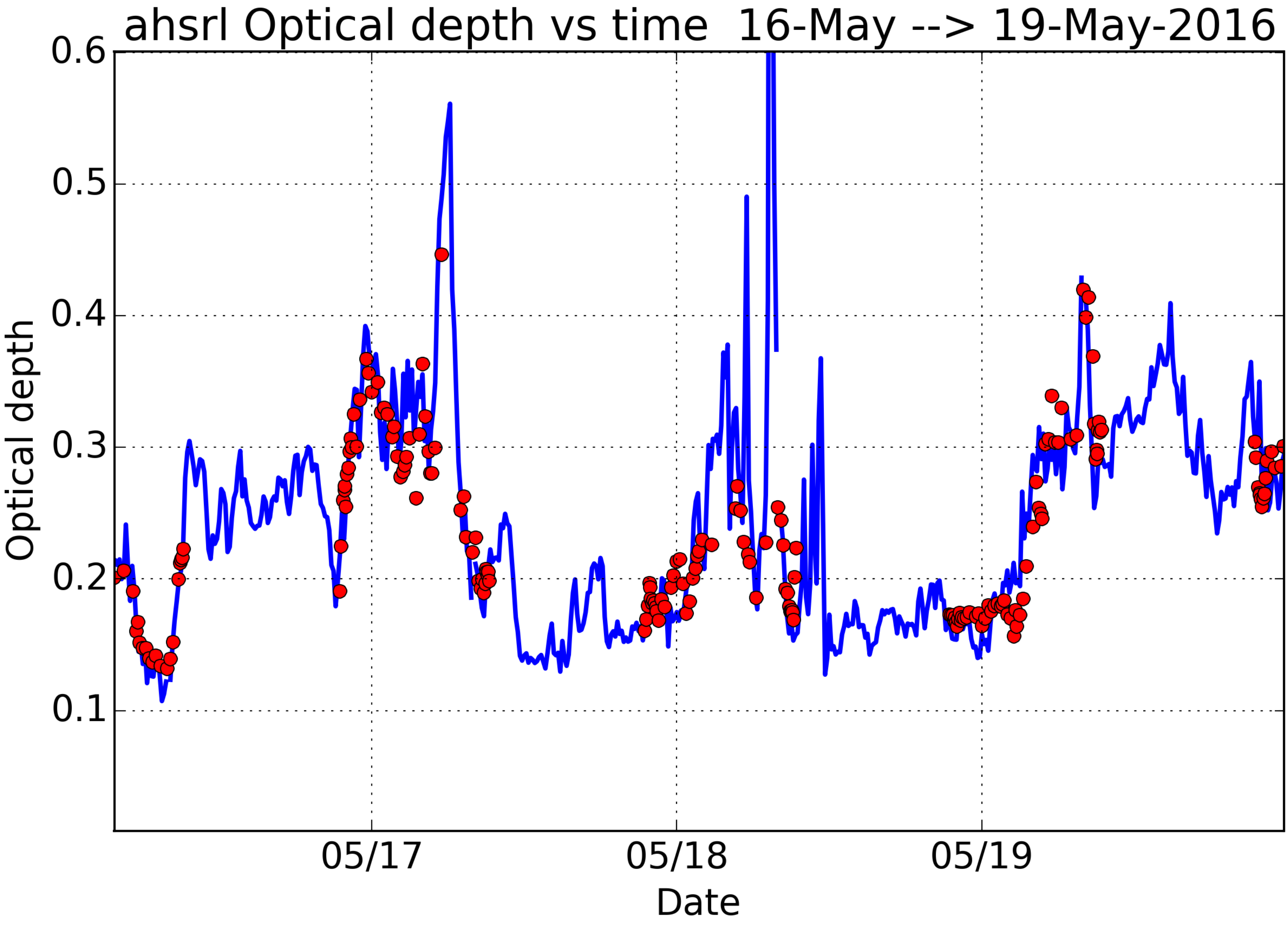


l wfov molecular profile 20-Oct-2013 18:00 --> 21-(
wfov * 450
wfov
mol
Altitude (km)
0
2
4
6
8
10
10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^{0} 10^{1}
wfov counts

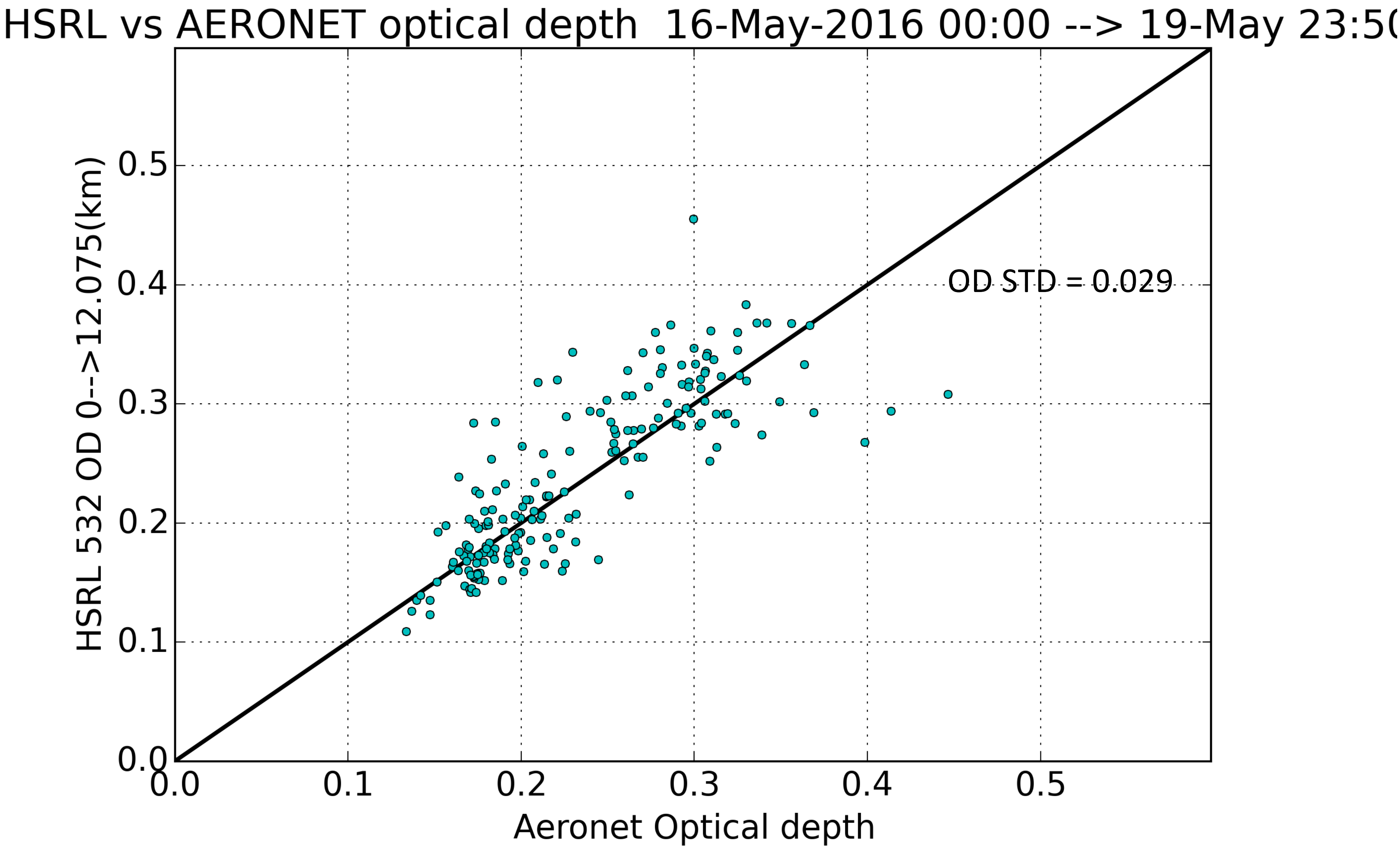


(current WFOV_MOL/MOL) / (WFOV/MOL when geo correction was determined)

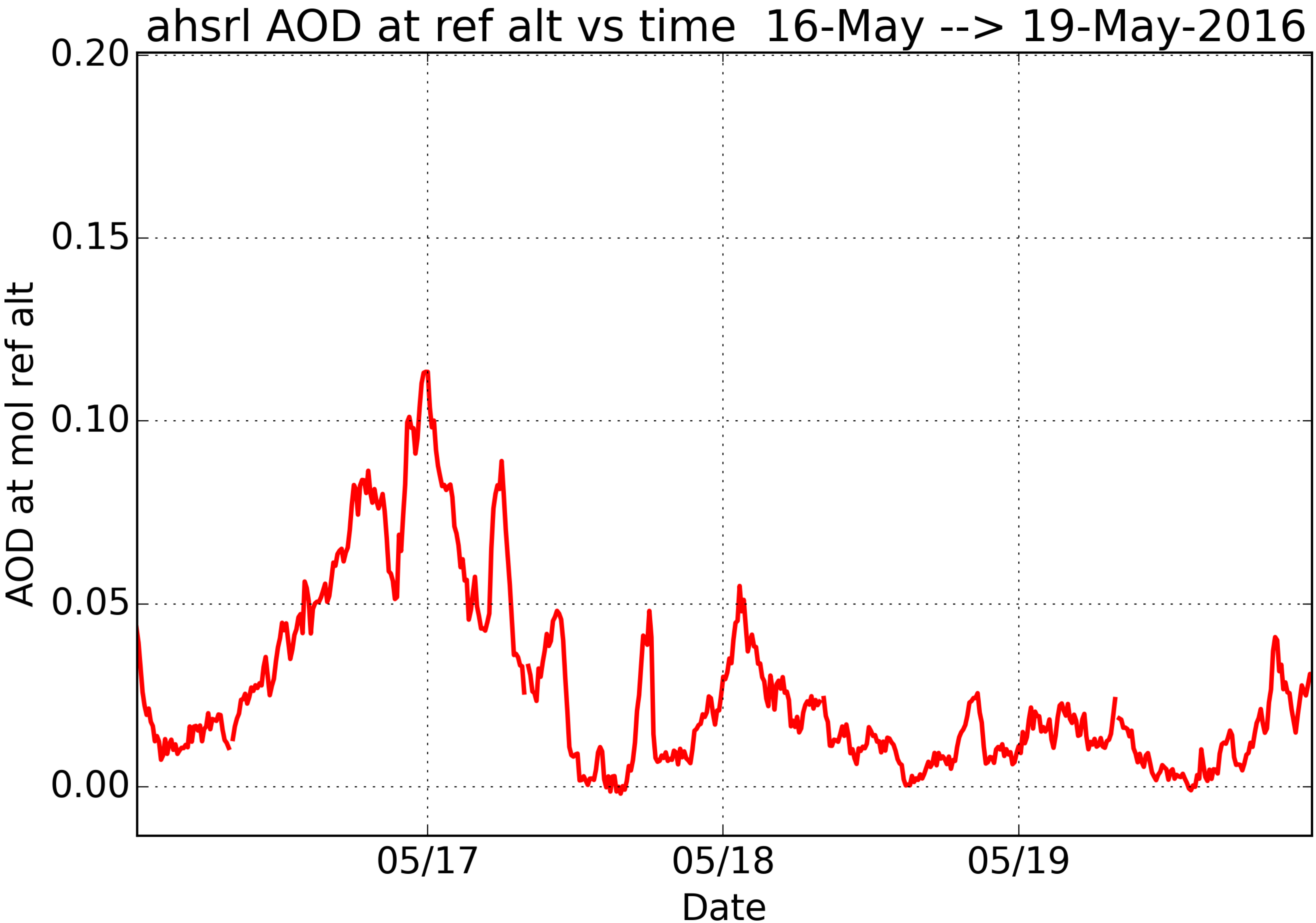

ahsrl extinction--Savitsky_Golay, dz=630.0,dt=600 16-May-2016
Altitude--msl (km)
0
2
4
6
8
10
05/16
05/17
05/18
05/19
Date
10^{-3}
10^{-4}
10^{-5}
10^{-6}
1/m



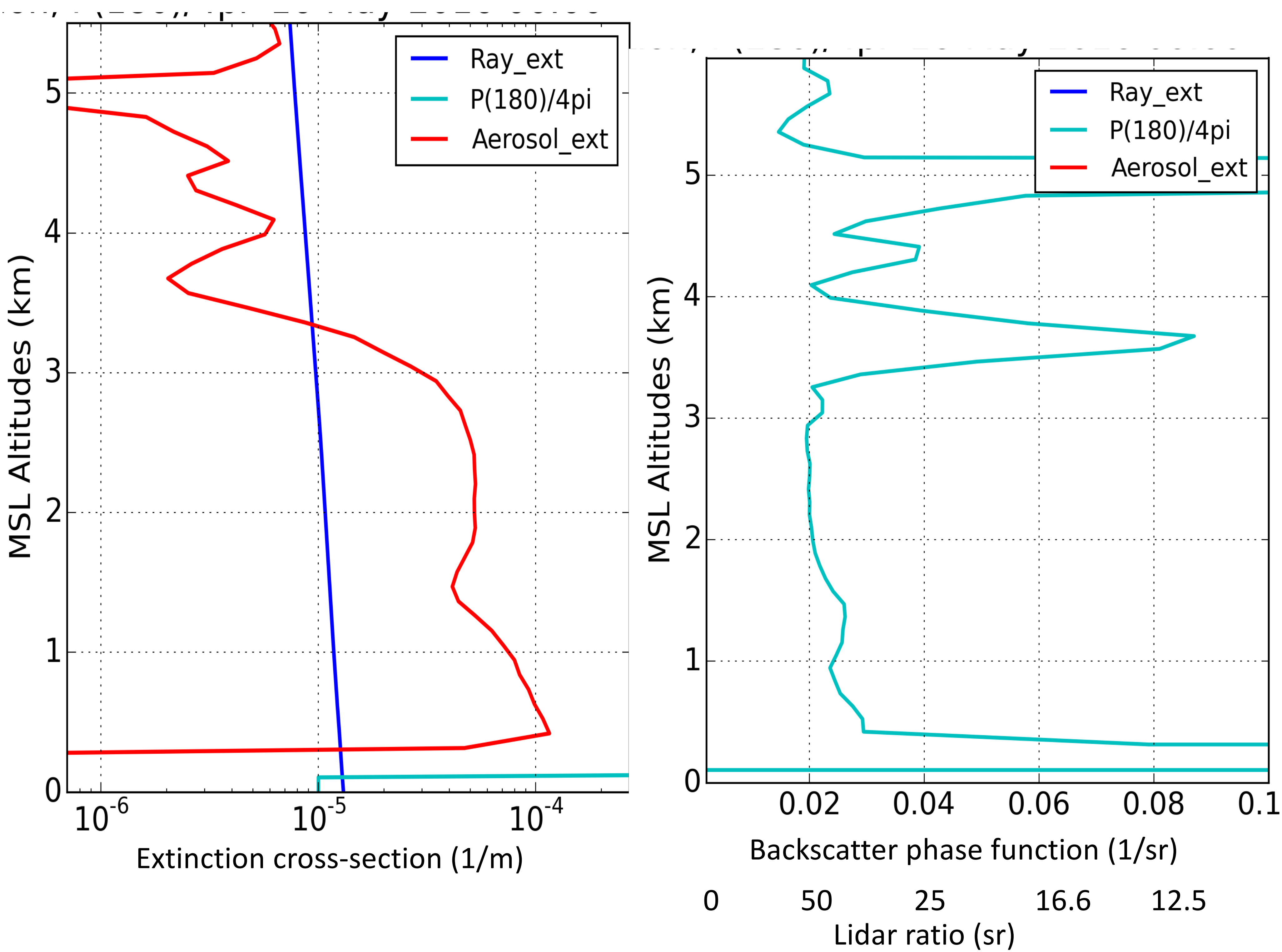
ahsrl Optical depth vs time 16-May --> 19-May-2016
Optical depth
Date
0.6
0.5
0.4
0.3
0.2
0.1
05/17
05/18
05/19



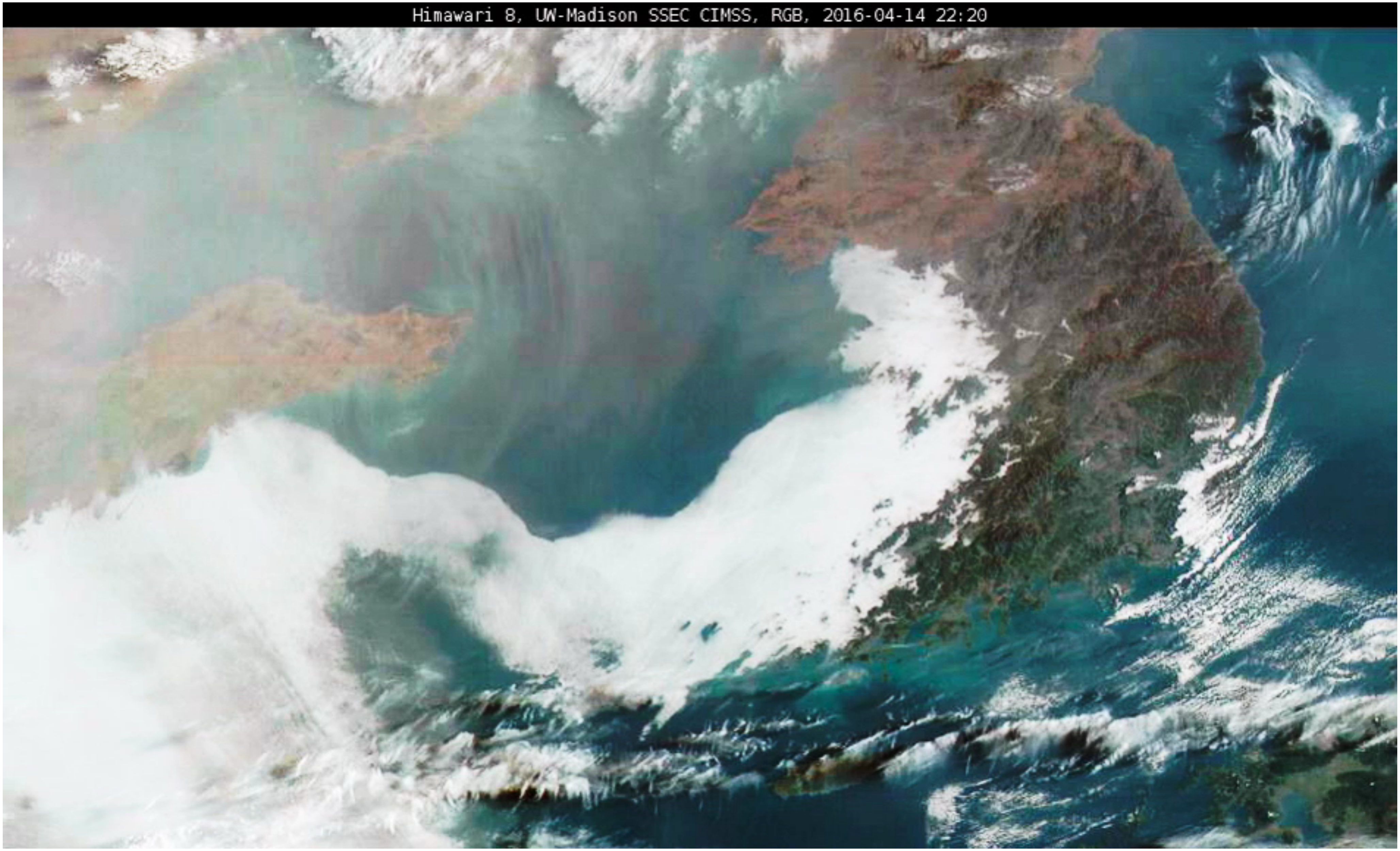
HSRL vs AERONET optical depth 16-May-2016 00:00 --> 19-May 23:5(
HSRL 532 OD 0-->12.075(km)
Aeronet Optical depth
OD STD = 0.029
0.0
0.1
0.2
0.3
0.4
0.5

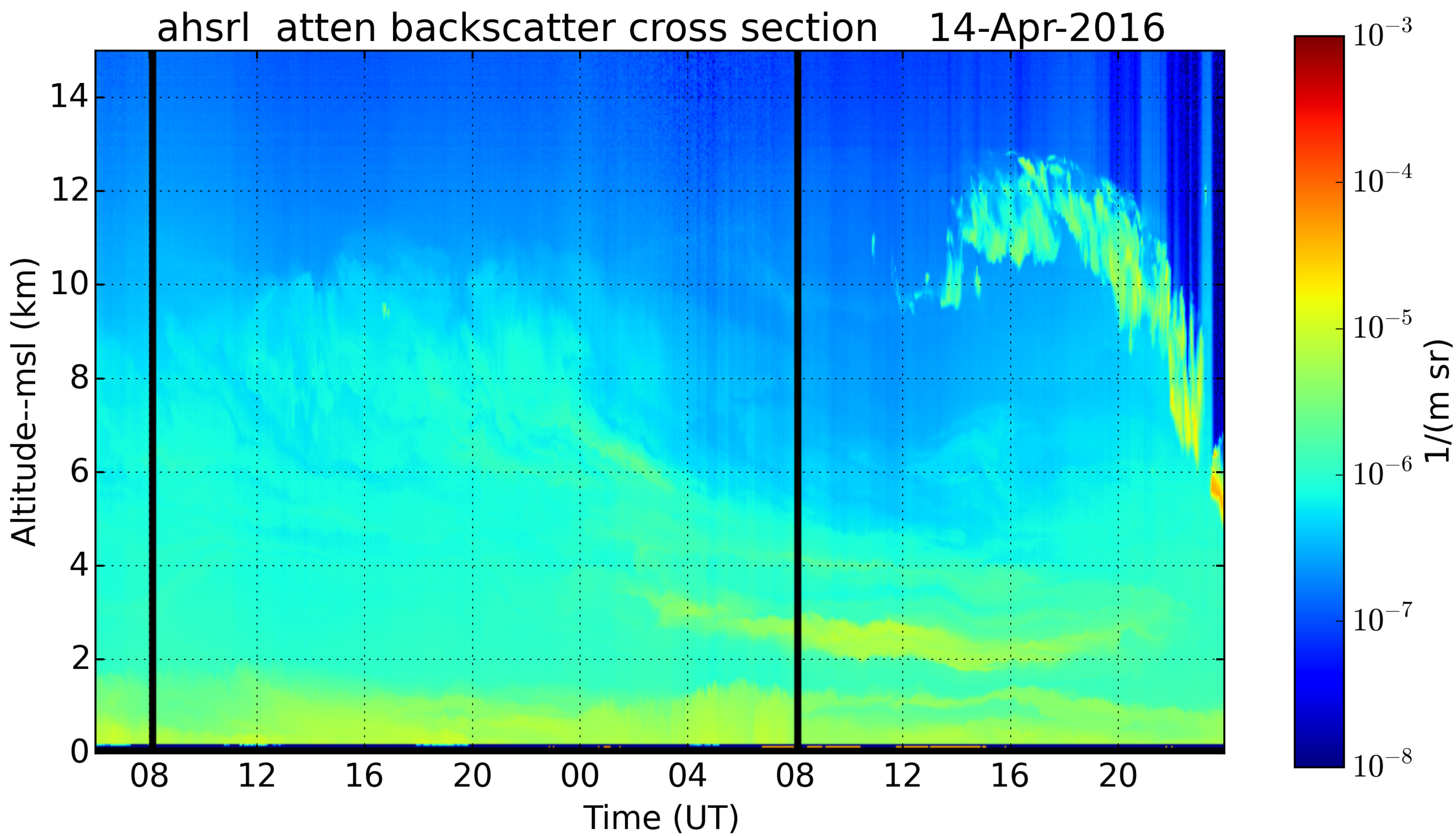


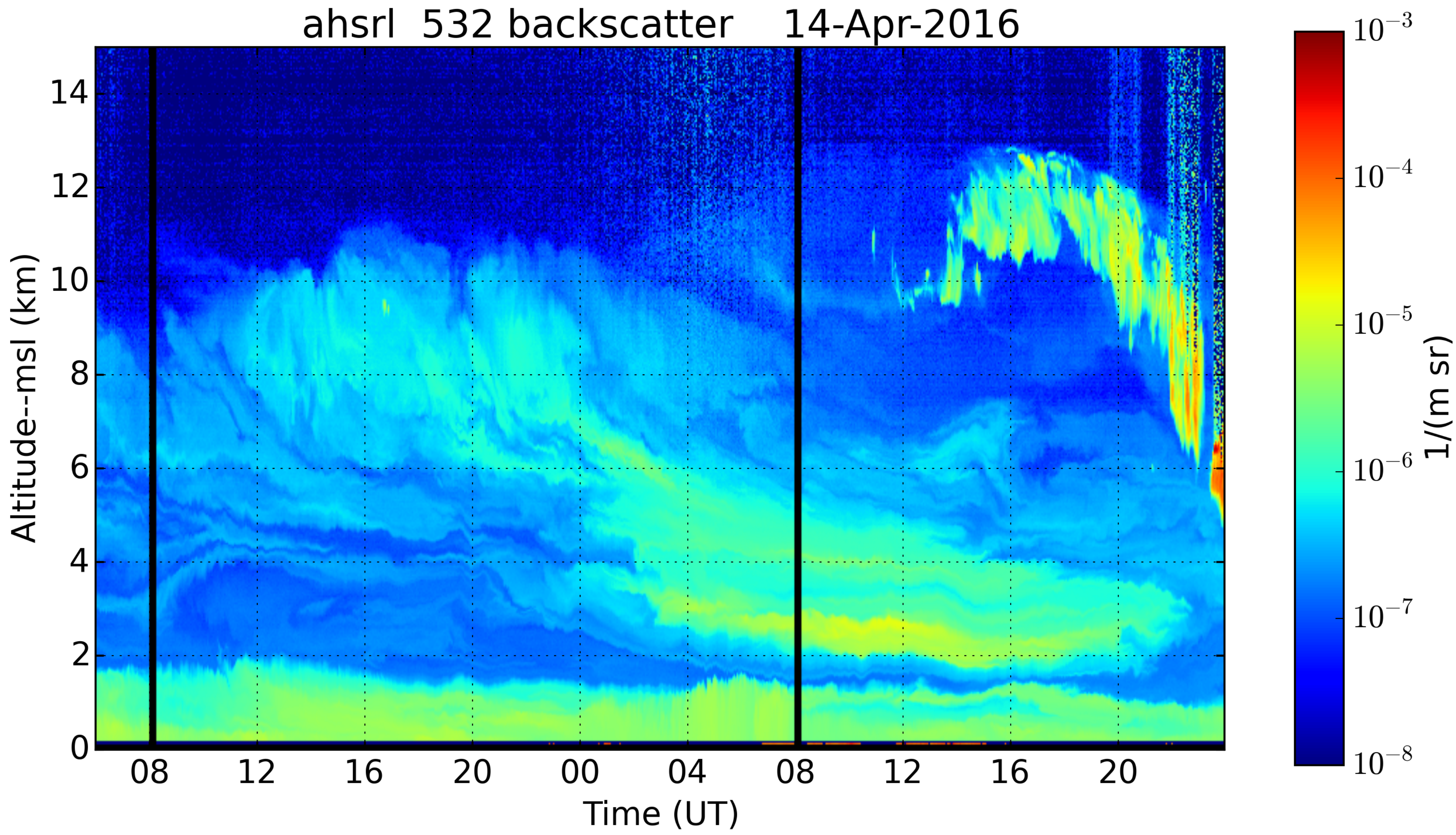
ahsrl AOD at ref alt vs time 16-May --> 19-May-2016
0.20
0.15
0.10
0.05
0.00
AOD at mol ref alt
05/17
05/18
05/19
Date



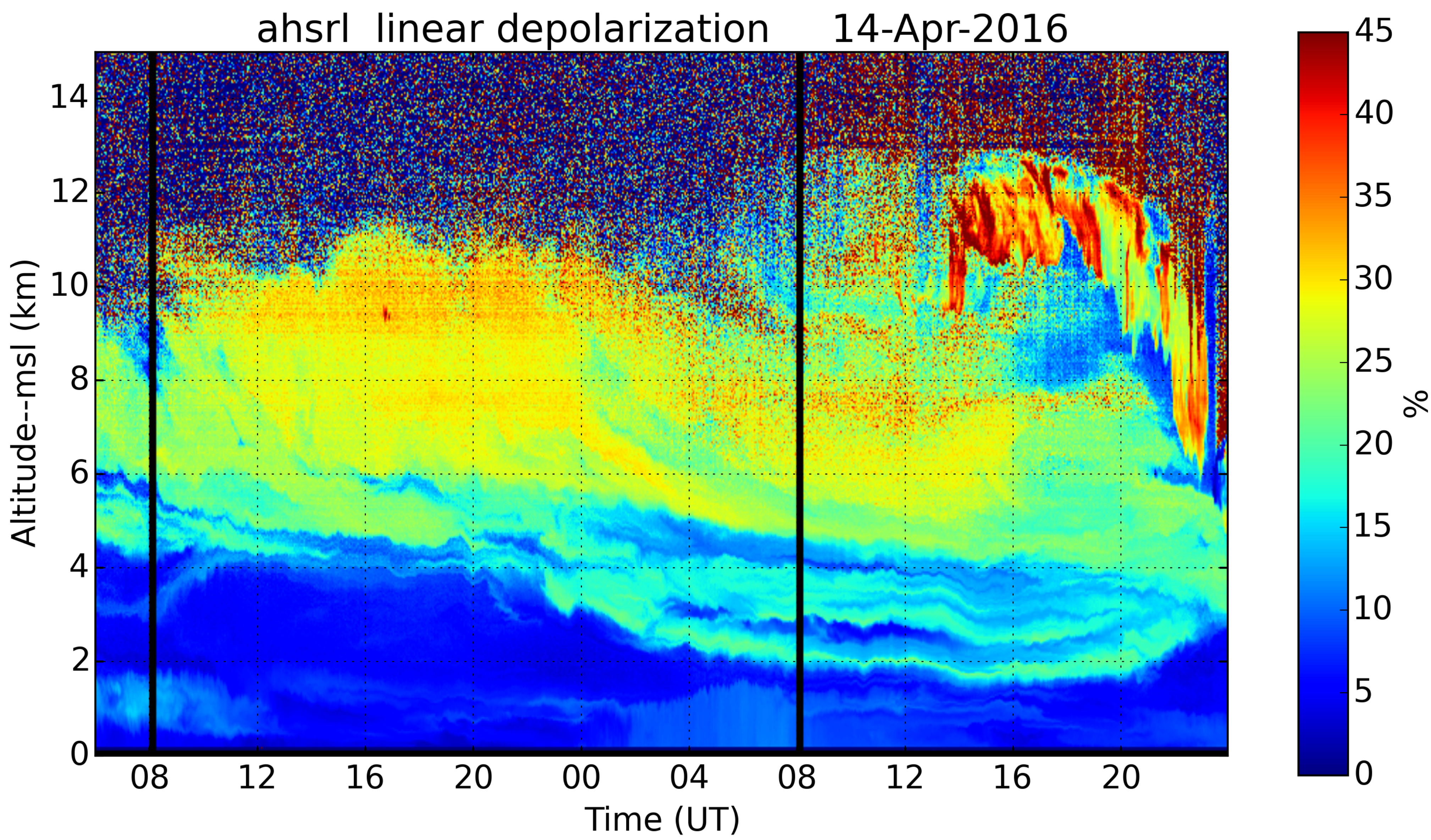
Ray_ext
P(180)/4pi
Aerosol_ext
MSL Altitudes (km)
0
1
2
3
4
5
10^{-6}
10^{-5}
10^{-4}
Extinction cross-section (1/m)
Ray_ext
P(180)/4pi
Aerosol_ext
MSL Altitudes (km)
0
1
2
3
4
5
0.02
0.04
0.06
0.08
0.1
Backscatter phase function (1/sr)
0
50
25
16.6
12.5
Lidar ratio (sr)


Himawari 8, UW-Madison SSEC CIMSS, RGB, 2016-04-14 22:20

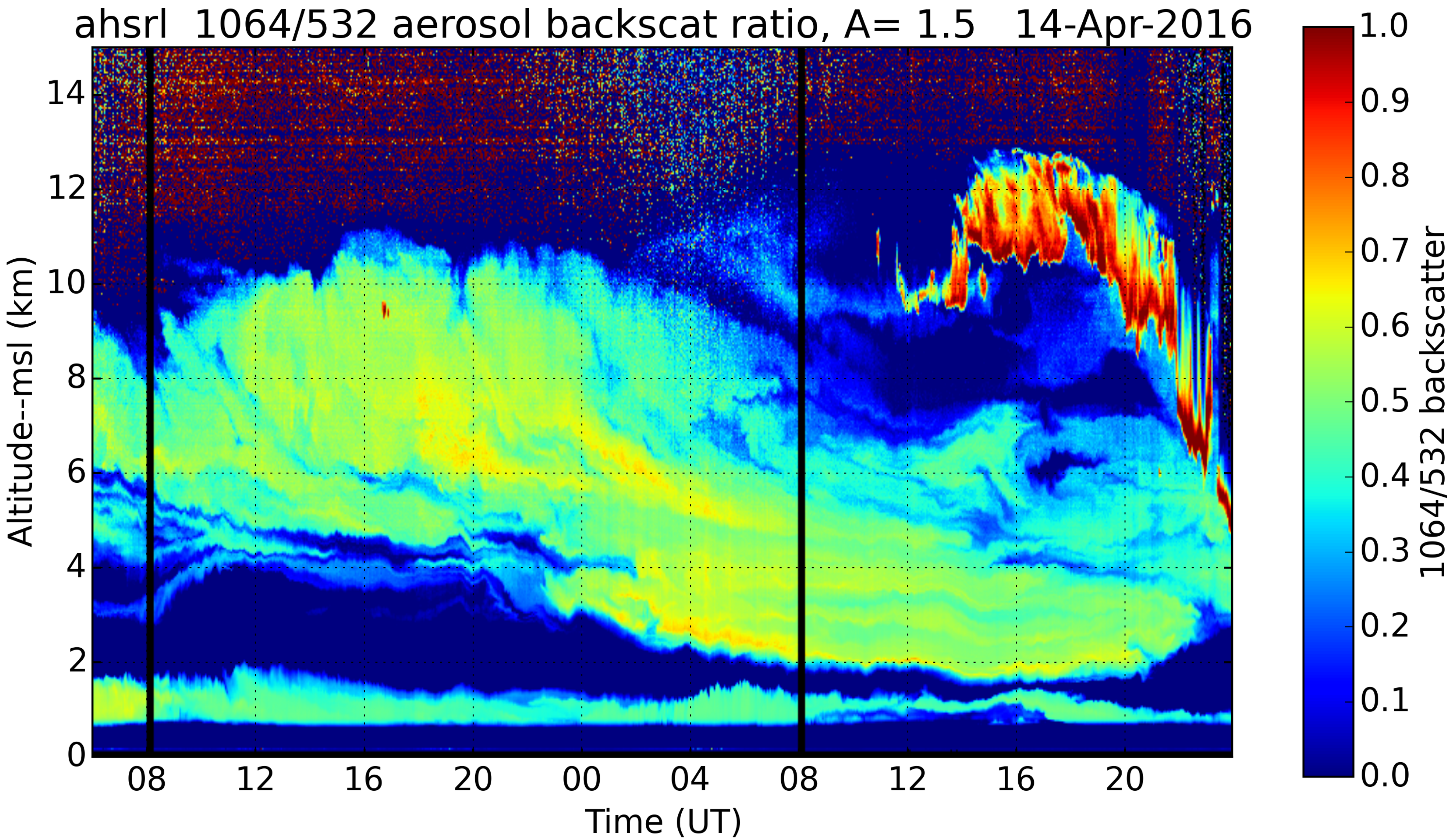

ahsrl atten backscatter cross section 14-Apr-2016
Altitude--msl (km)
0
2
4
6
8
10
12
14
08
12
16
20
00
04
08
12
16
20
Time (UT)
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
1/(m sr)



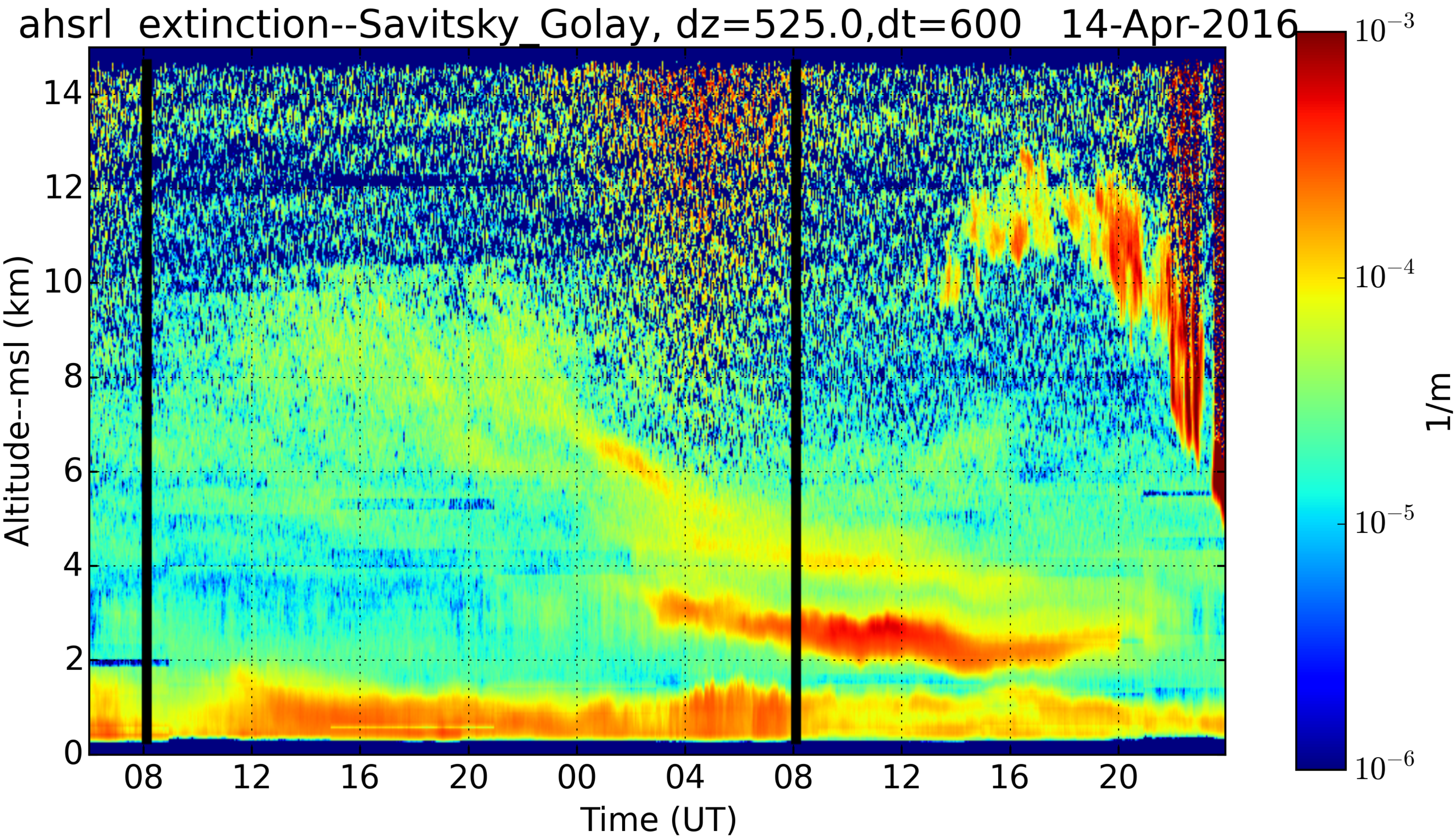
ahsrl 532 backscatter 14-Apr-2016
Altitude--msl (km)
0
2
4
6
8
10
12
14
08
12
16
20
00
04
08
12
16
20
Time (UT)
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
1/(m sr)

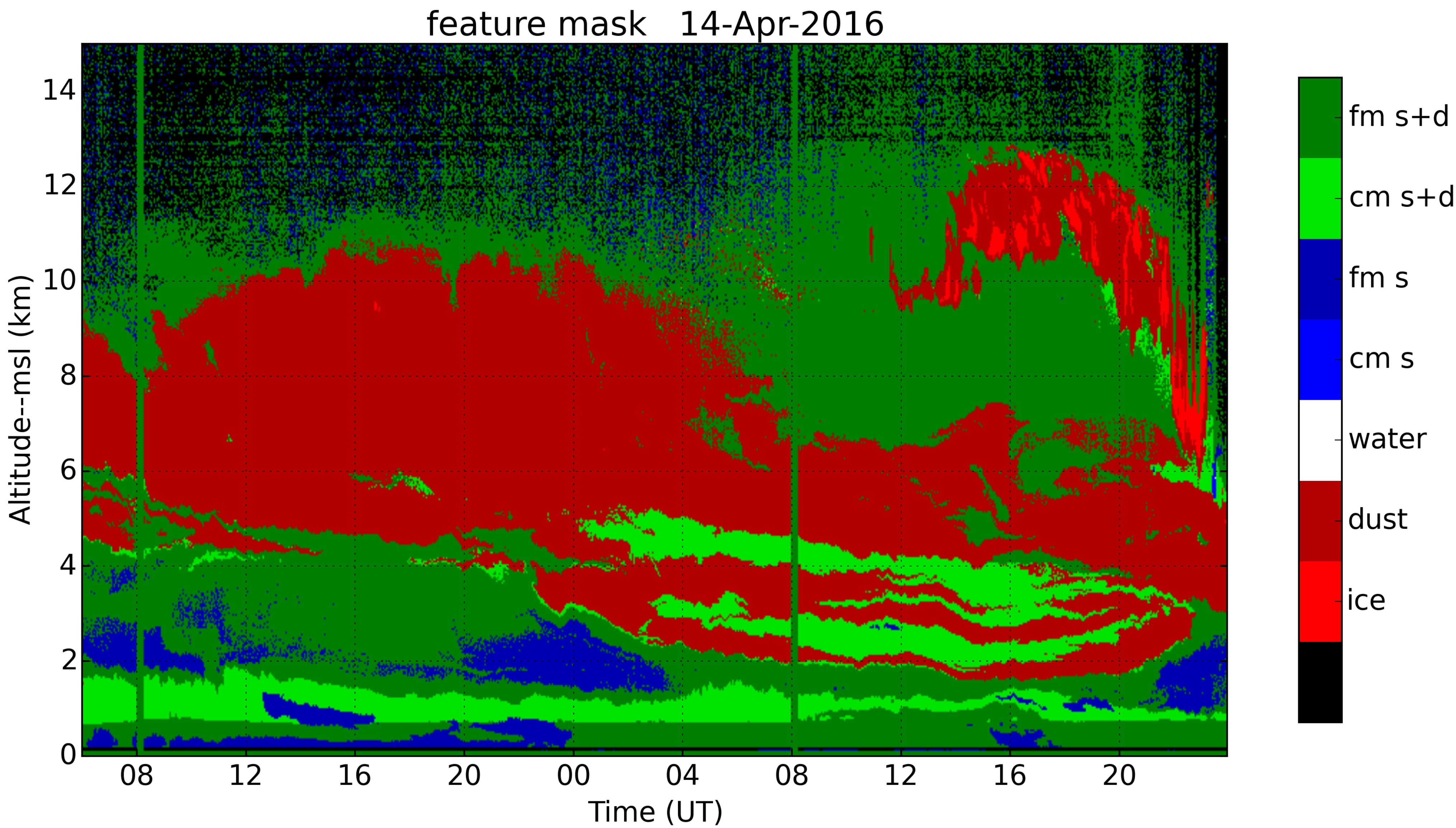


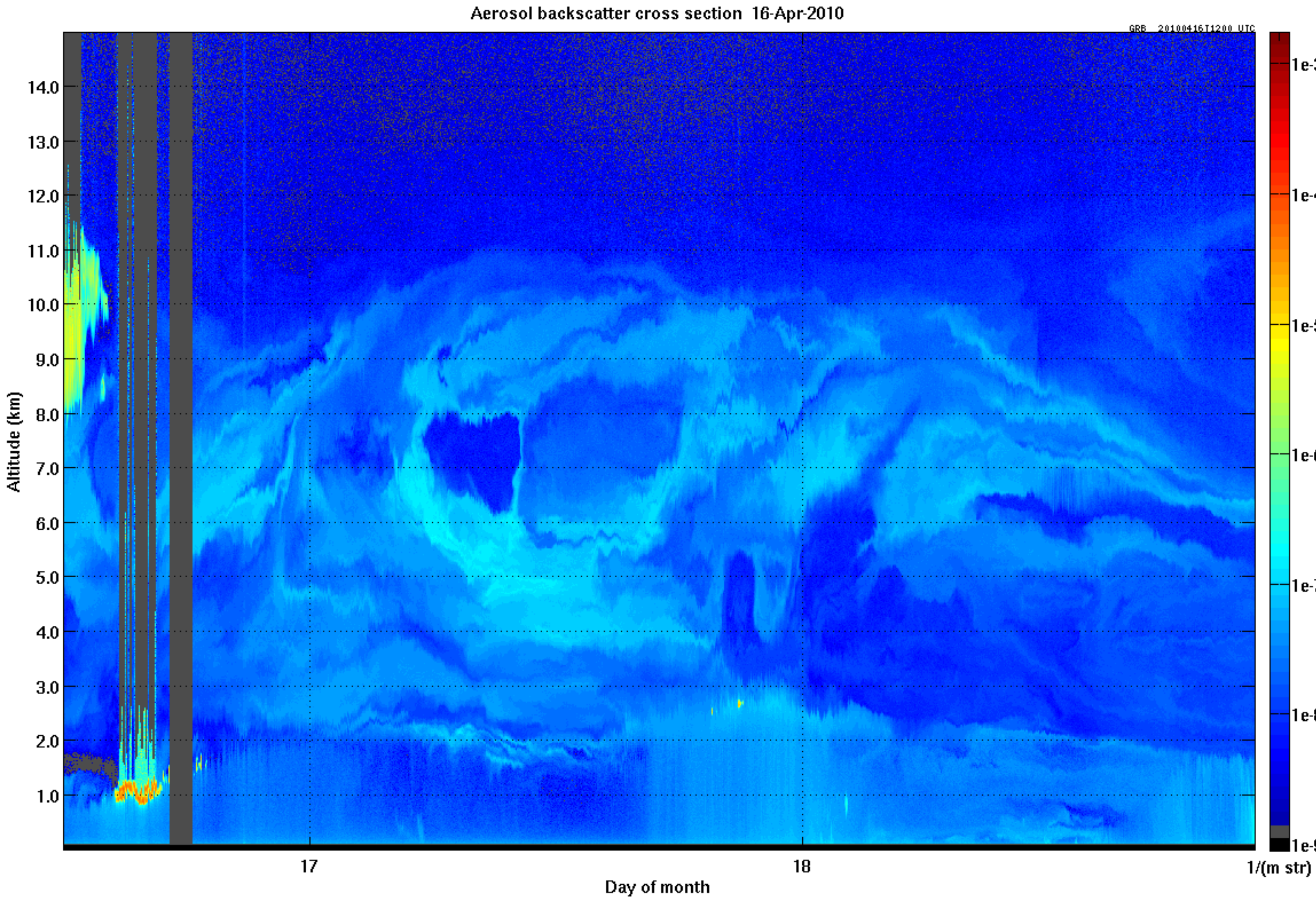
ahsrl linear depolarization 14-Apr-2016
Altitude--msl (km)
0
2
4
6
8
10
12
14
08
12
16
20
00
04
08
12
16
20
Time (UT)
0
5
10
15
20
25
30
35
40
45
%



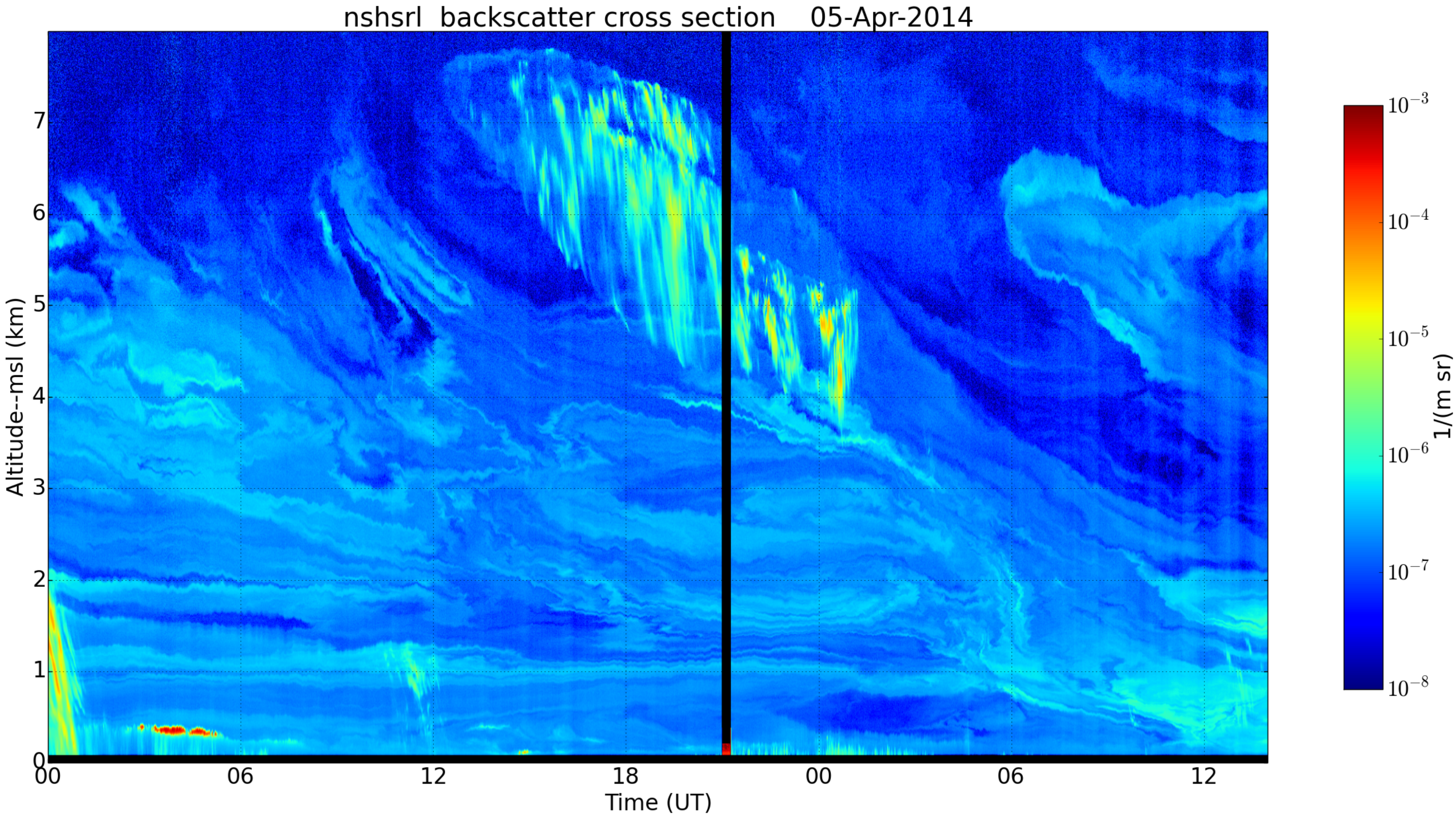
ahsrl 1064/532 aerosol backscat ratio, A= 1.5 14-Apr-2016
Altitude--msl (km)
0
2
4
6
8
10
12
14
08
12
16
20
00
04
08
12
16
20
Time (UT)
1064/532 backscatter
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0


ahsrl extinction--Savitsky_Golay, dz=525.0,dt=600 14-Apr-2016
Altitude--msl (km)
Time (UT)
1/m
0
2
4
6
8
10
12
14
08
12
16
20
00
04
08
12
16
20
10^{-3}
10^{-4}
10^{-5}
10^{-6}

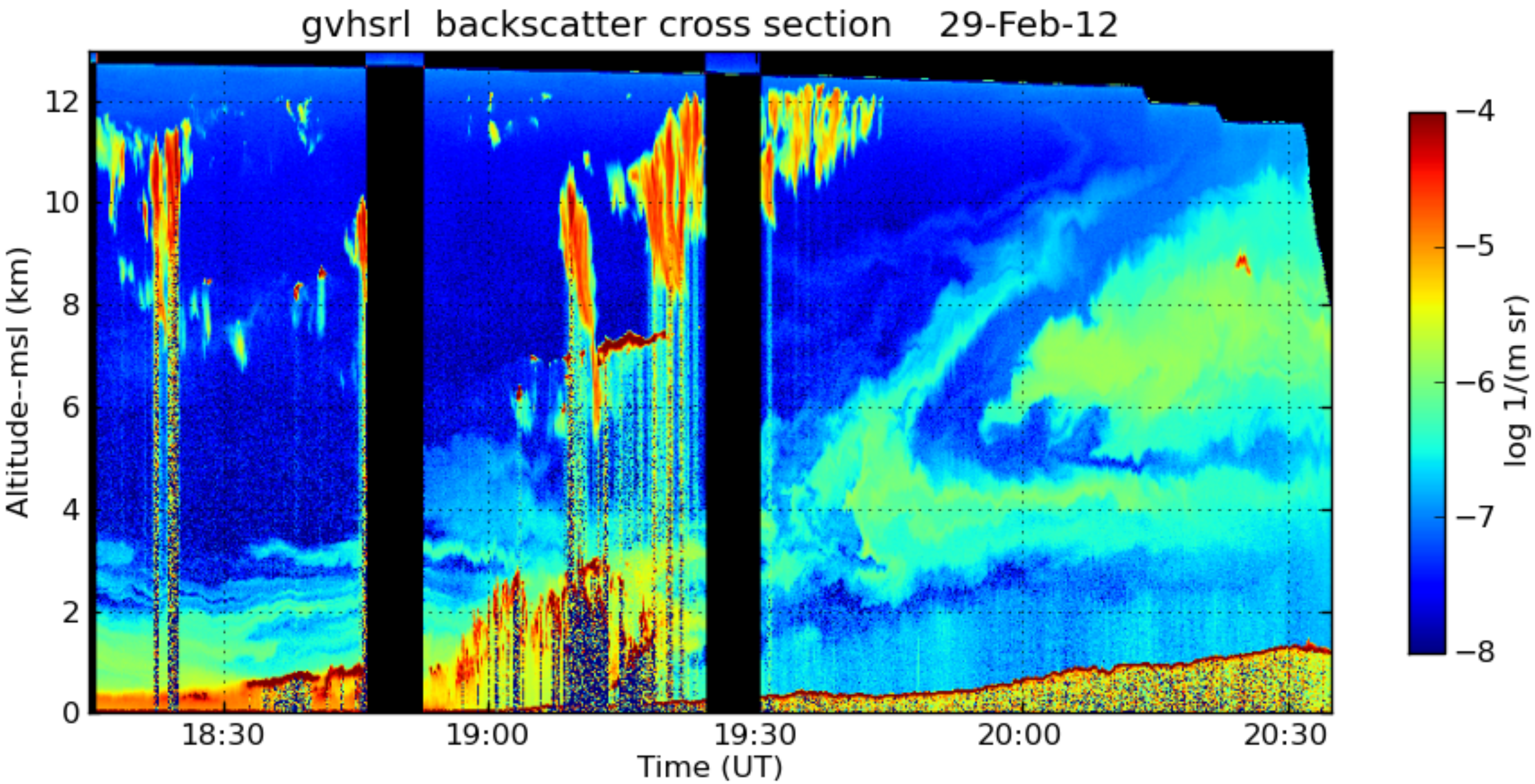

feature mask 14-Apr-2016
Altitude--msl (km)
0
2
4
6
8
10
12
14
08
12
16
20
00
04
08
12
16
20
Time (UT)
fm s+d
cm s+d
fm s
cm s
water
dust
ice

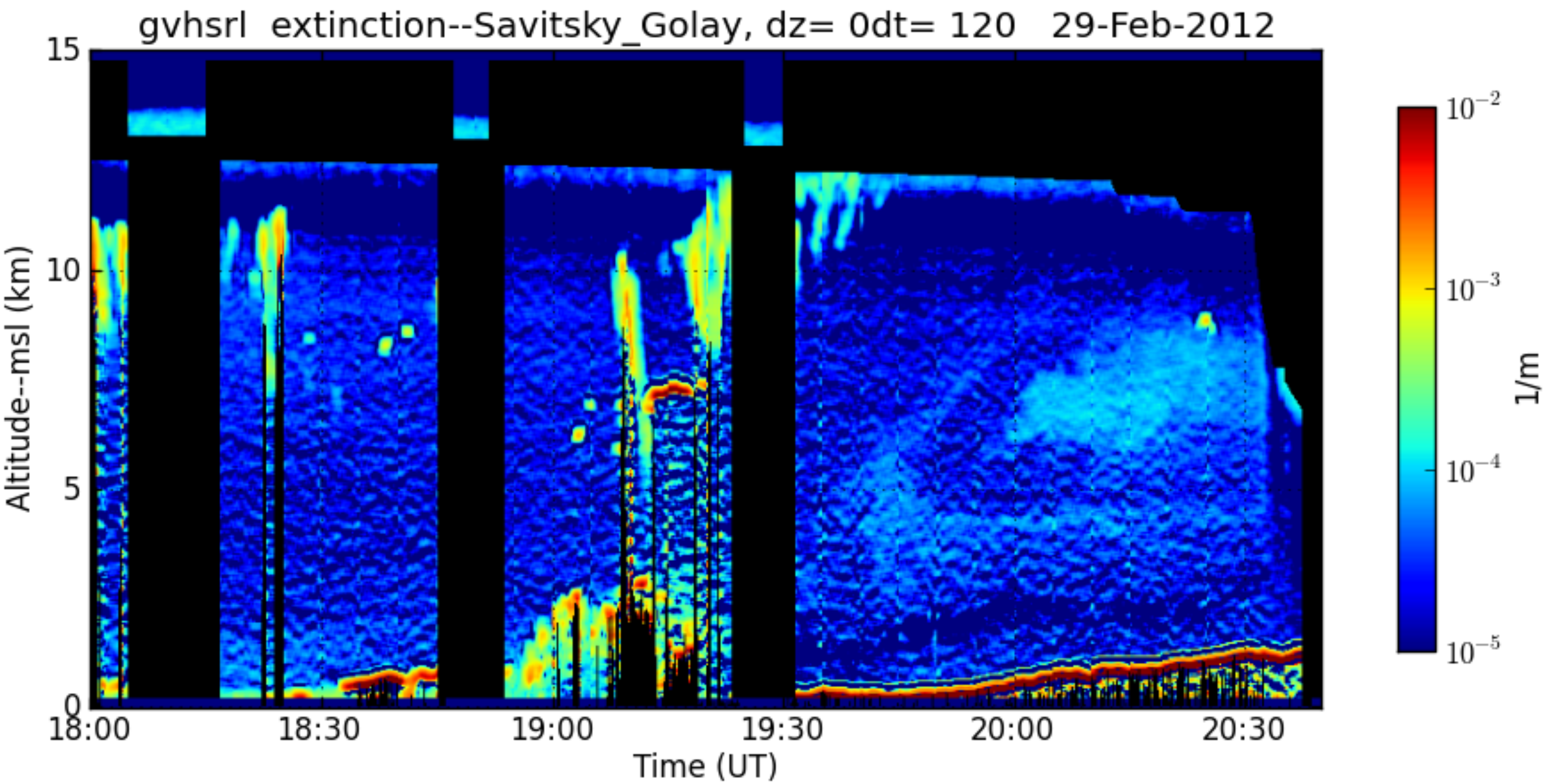


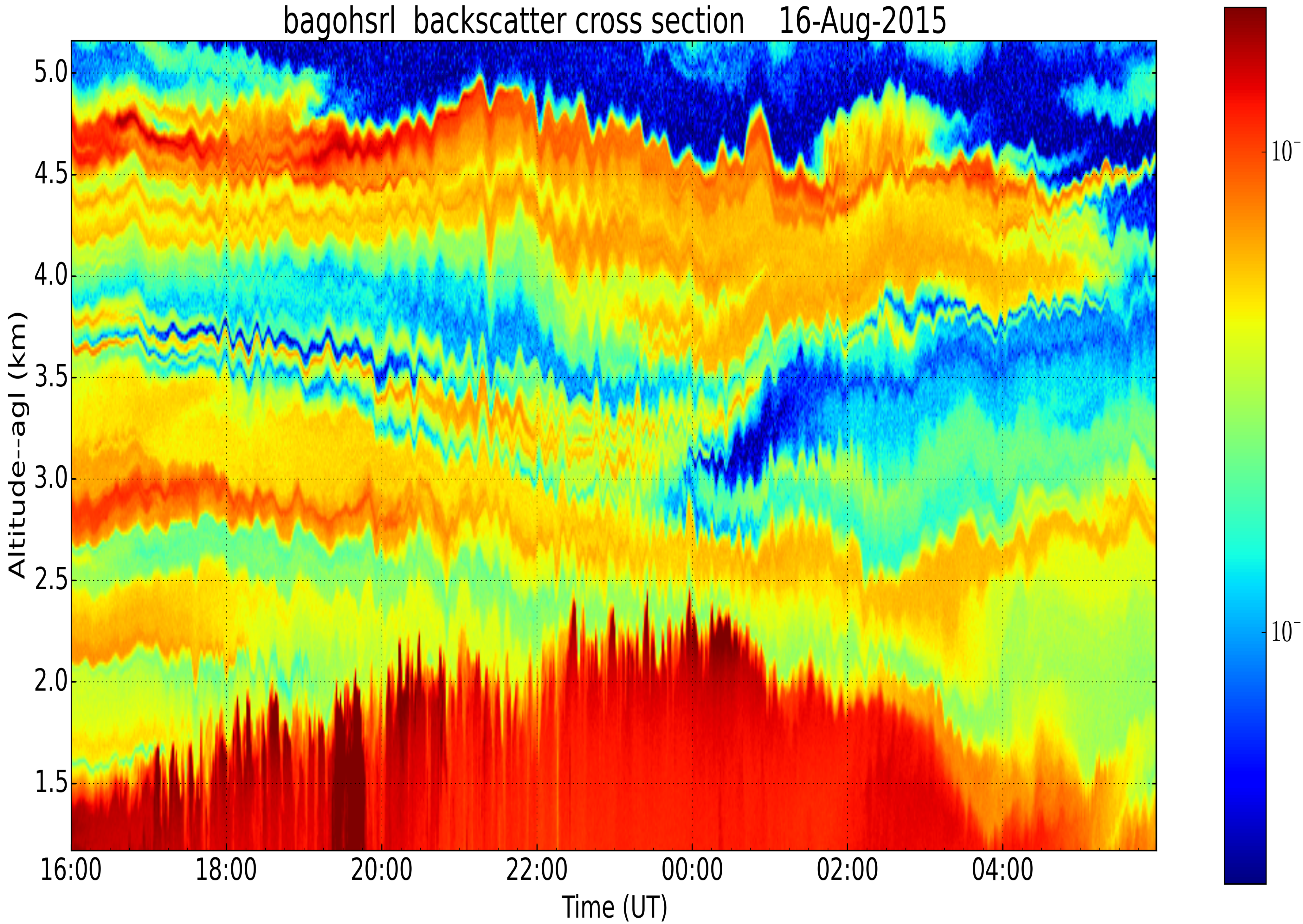
Aerosol backscatter cross section 16-Apr-2010
GRB 20100416T1200 UTC
Altitude (km)
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
17
18
Day of month
1e-3
1e-4
1e-5
1e-6
1e-7
1e-8
1e-9
1/(m str)



nshsrl backscatter cross section 05-Apr-2014
Altitude--msl (km)
0
1
2
3
4
5
6
7
Time (UT)
00
06
12
18
00
06
12
1/(m sr)
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}


gvhsrl backscatter cross section 29-Feb-12
Altitude--msl (km)
0
2
4
6
8
10
12
18:30
19:00
19:30
20:00
20:30
Time (UT)
log 1/(m sr)
−4
−5
−6
−7
−8


gvhsrl extinction--Savitsky_Golay, dz= 0dt= 120   29-Feb-2012
Altitude--msl (km)
15
10
5
0
18:00
18:30
19:00
19:30
20:00
20:30
Time (UT)
10^{-2}
10^{-3}
10^{-4}
10^{-5}
1/m


bagohsrl backscatter cross section 16-Aug-2015
Altitude--agl (km)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
16:00
18:00
20:00
22:00
00:00
02:00
04:00
Time (UT)
10⁻
10⁻


Looking for future where
High Spectral Resolution
Lidars can be widely deployed