MPL polarization sensitivity and derived linear depolarization ratio

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Micropulse Lidar (MPL) in ARM

MPL systems deployed at each site

- SGP since 1994
- NSA since 1999
- TWP 1997, 1999, 2003
- AMF 2004-current

But initially none with polarization sensitivity

- Until Nov. 2003 in support of MPACE, prototype MPL-PS operated at Barrow in proximity of PDL and HSRL.

Dates of MPLpol installations

- NSA, MPL-PS 2003/11/12 – 2006/09/27
- SGP C1: 2006/05/02
- TWP C3: 2006/08/25
- NSA C1: 2006/09/28
- TWP C1: 2007/01/31
- TWP C2: 2006/11/27
- AMF FKB: 2007/03/17

Micropulse Lidar System

Laptop Computer

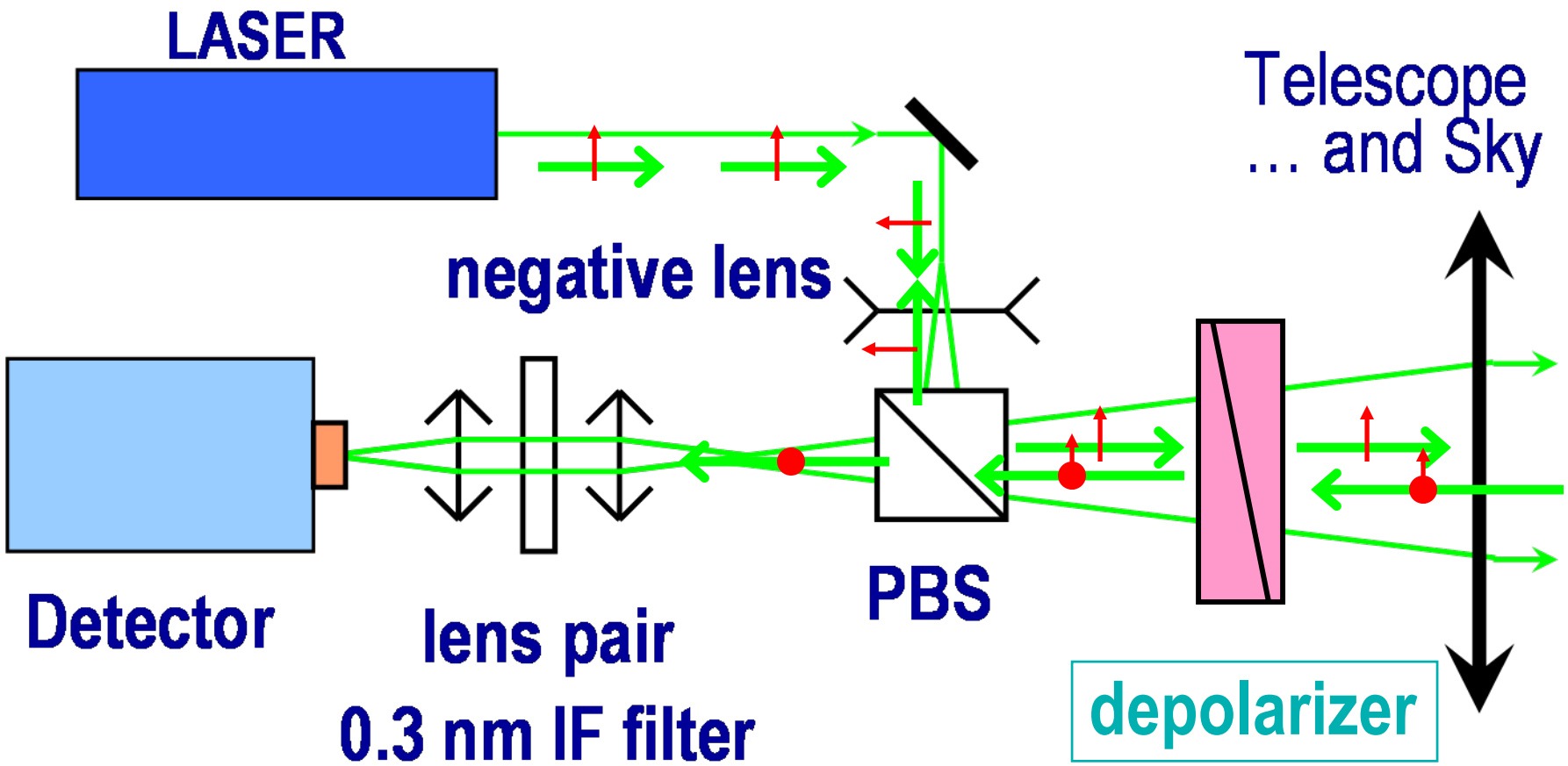
LASER Supply

LIDAR Control

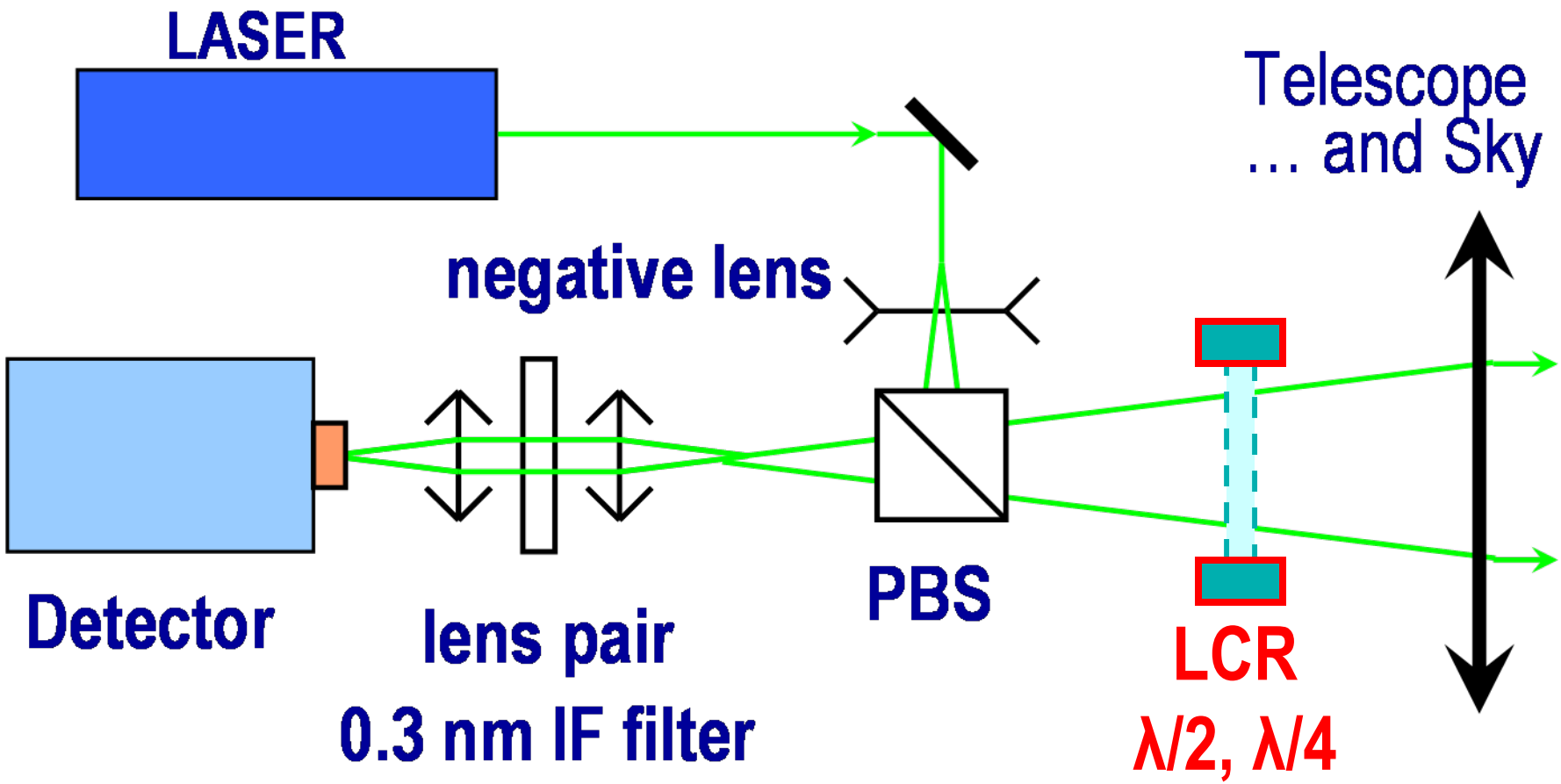
Telescope / Transceiver

Optics Enclosure

MPL General Optical Layout



MPL with Liquid Crystal Retarder

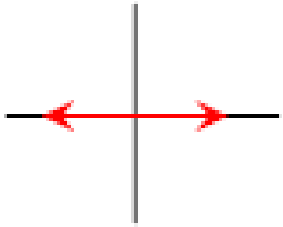


Polarization-Sensitive Measurement

- Mode 1: LCR as half-wave retarder
  - Transmits / detects linearly polarized radiation
  - Mainly sensitive to non-spheres, ice, mineral dust
- Mode 2: LCR as quarter-wave retarder
  - Transmits/detects circularly polarized radiation
  - Mainly detects cloud droplets and spherical aerosols
- Alternates modes every few seconds
- But no loss compared to the MPL with depolarizer
- Linear Lidar depol ratio = crosspol / copol
- … but what is this MPL linear/circular hybrid really mean?

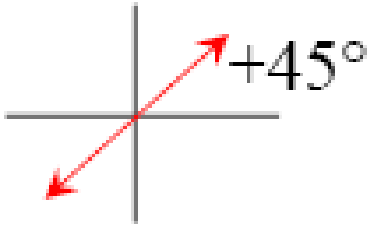
Elementary Stokes Vectors

LH



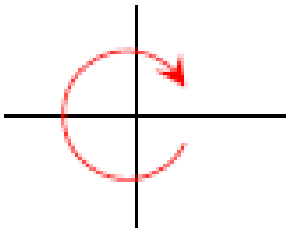
$$S = \begin{bmatrix} 1 \\ 1 \\ 0 \\ 0 \end{bmatrix}$$

LH + 45°



$$S = \begin{bmatrix} 1 \\ 0 \\ 1 \\ 0 \end{bmatrix}$$

rcp



$$S = \begin{bmatrix} 1 \\ 0 \\ 0 \\ 1 \end{bmatrix}$$

Mueller Matrix Operations

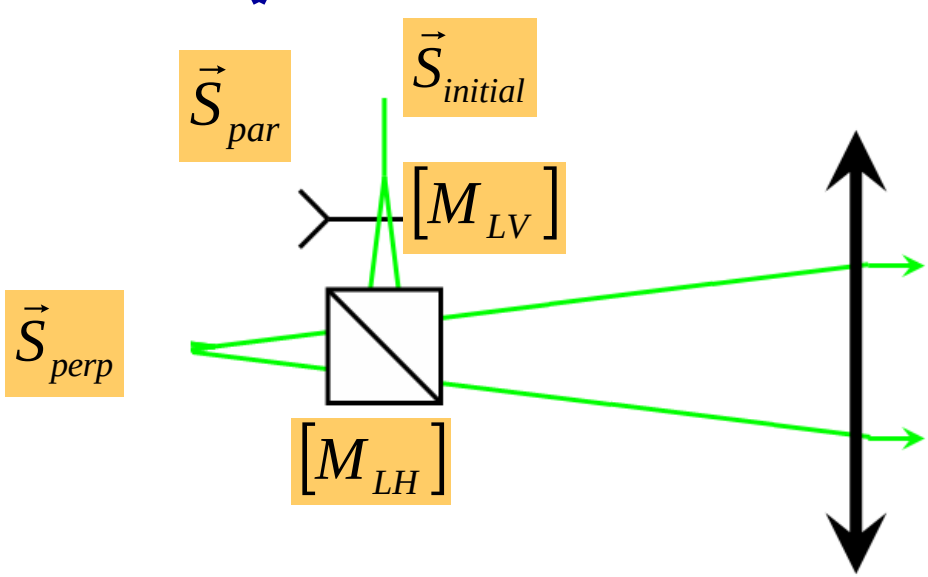
$$\vec{S}_{final} = [M]\vec{S}_{initial}$$

$$\vec{S}_{final} = [M_n][M_n]\ldots[M_2][M_1]\vec{S}_{initial}$$

Mueller operations for linear depol

$$\vec{S}_{perp} = [M_{LH}][M_{atm}][M_{LV}]\vec{S}_{initial}$$

$$\vec{S}_{par} = [M_{LV}][M_{atm}][M_{LV}]\vec{S}_{initial}$$



$$[M_{LV}] = \tfrac{1}{2}\begin{bmatrix} 1 & -1 & 0 & 0 \\ -1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

$$[M_{LH}] = \tfrac{1}{2}\begin{bmatrix} 1 & 1 & 0 & 0 \\ 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

$$[M_{atm}] = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1-d & 0 & 0 \\ 0 & 0 & d-1 & 0 \\ 0 & 0 & 0 & 2d-1 \end{bmatrix}$$

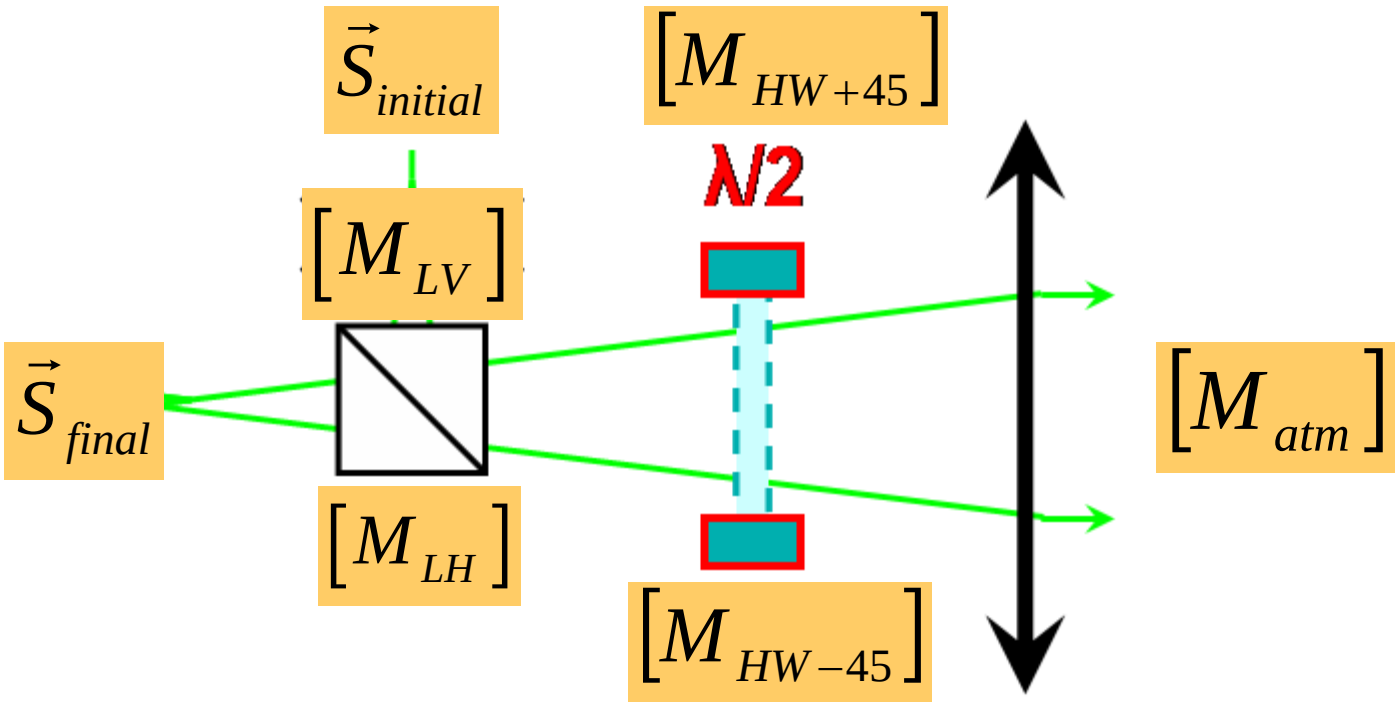
Linear depol ratio defined

$$\vec{S}_{perp} = \begin{bmatrix} d/2 \\ d/2 \\ 0 \\ 0 \end{bmatrix} \qquad \vec{S}_{par} = \begin{bmatrix} 1 - d/2 \\ d/2 - 1 \\ 0 \\ 0 \end{bmatrix}$$

$$\delta_{linear} = \frac{S_1(perp)}{S_1(par)} = \frac{d}{2-d}$$

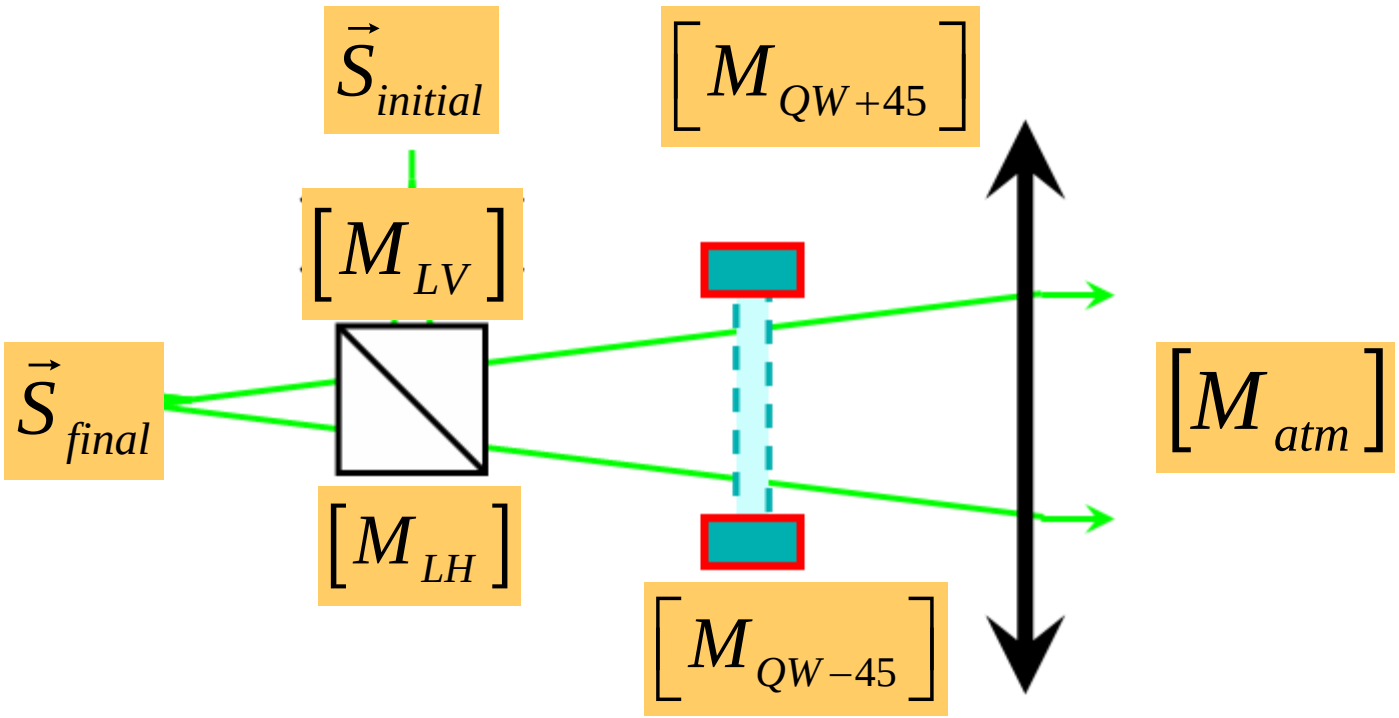
Mueller operations for MPL half-wave

$$\vec{S}(\lambda/2)_{final} = [M_{LH}][M_{HW-45}][M_{atm}][M_{HW+45}][M_{LV}]\vec{S}_{initial}$$



Mueller operations for MPL quarter-wave

$$\vec{S}(\lambda/4)_{final} = [M_{LH}][M_{QW-45}][M_{atm}][M_{QW+45}][M_{LV}]\vec{S}_{initial}$$



MPL depol ratio in perspective

MPL mode 1: $S_1(\lambda/2) = d/2$

MPL mode 2: $S_1(\lambda/4) = 1 - d$

$$\delta_{\mathrm{MPL}} = \frac{d}{2(1-d)}$$

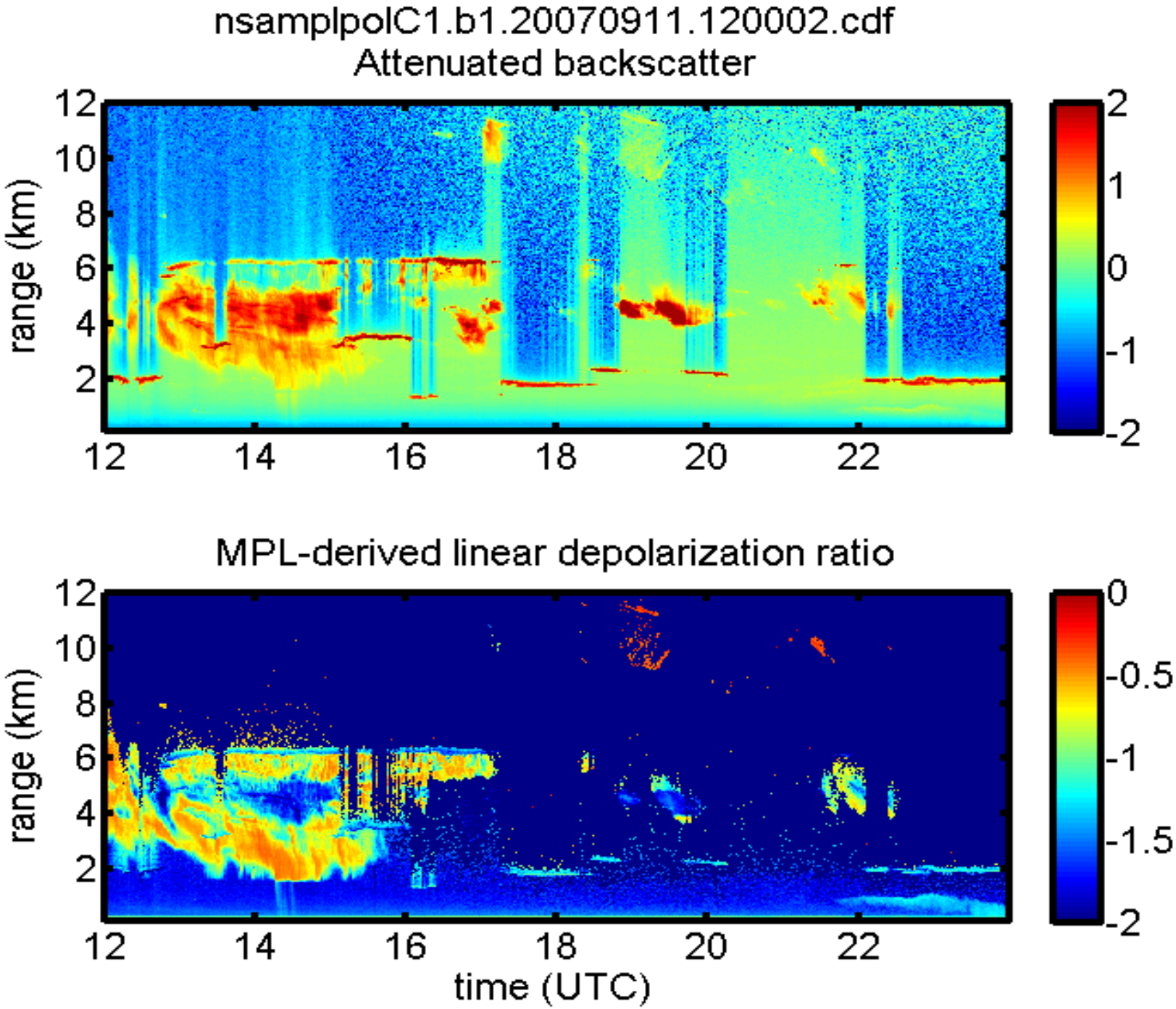
$$\delta_{\mathrm{MPL}} = \frac{\delta_{\mathrm{circ}}}{2} = \frac{\delta_{\mathrm{linear}}}{1 - \delta_{\mathrm{linear}}}$$

$$\delta_{\mathrm{circ}} = d/(1-d)$$

$$\delta_{\mathrm{Linear}} = d/(2-d)$$

Summary

- Demonstrable sensitivity to depolarization by cloud and aerosol.
- Although a “hybrid” measurement, connections to common depol ratios are clear
- Prototype data from Nov. 2003
- New MPL-PS data starting at SGP, TWP-Darwin, AMF, and soon at all ARM sites.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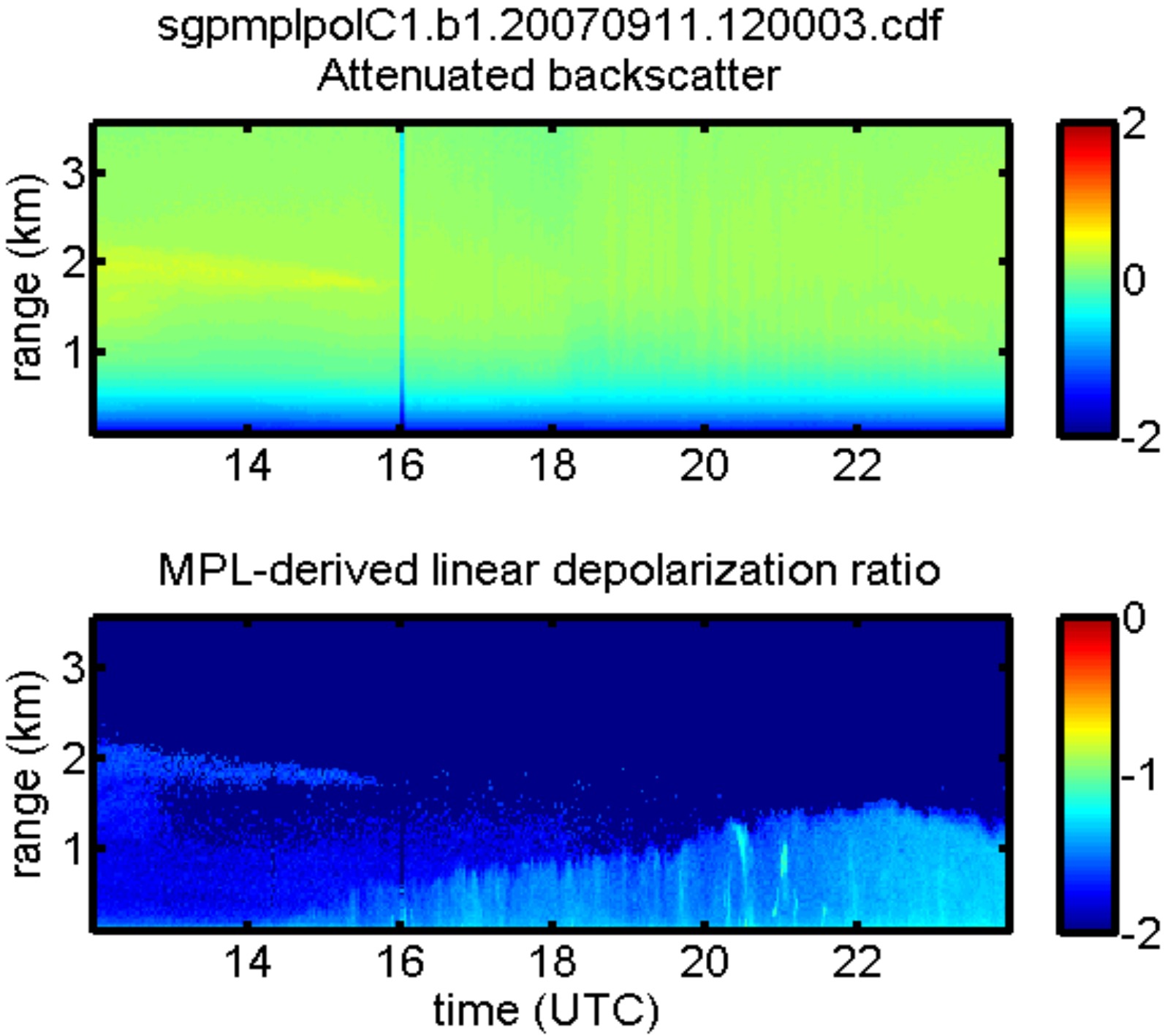
Attenuated backscatter
range (km)
12
10
8
6
4
2
12
14
16
18
20
22
2
1
0
-1
-2
MPL-derived linear depolarization ratio
range (km)
12
10
8
6
4
2
12
14
16
18
20
22
time (UTC)
0
-0.5
-1
-1.5
-2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Attenuated backscatter
range (km)
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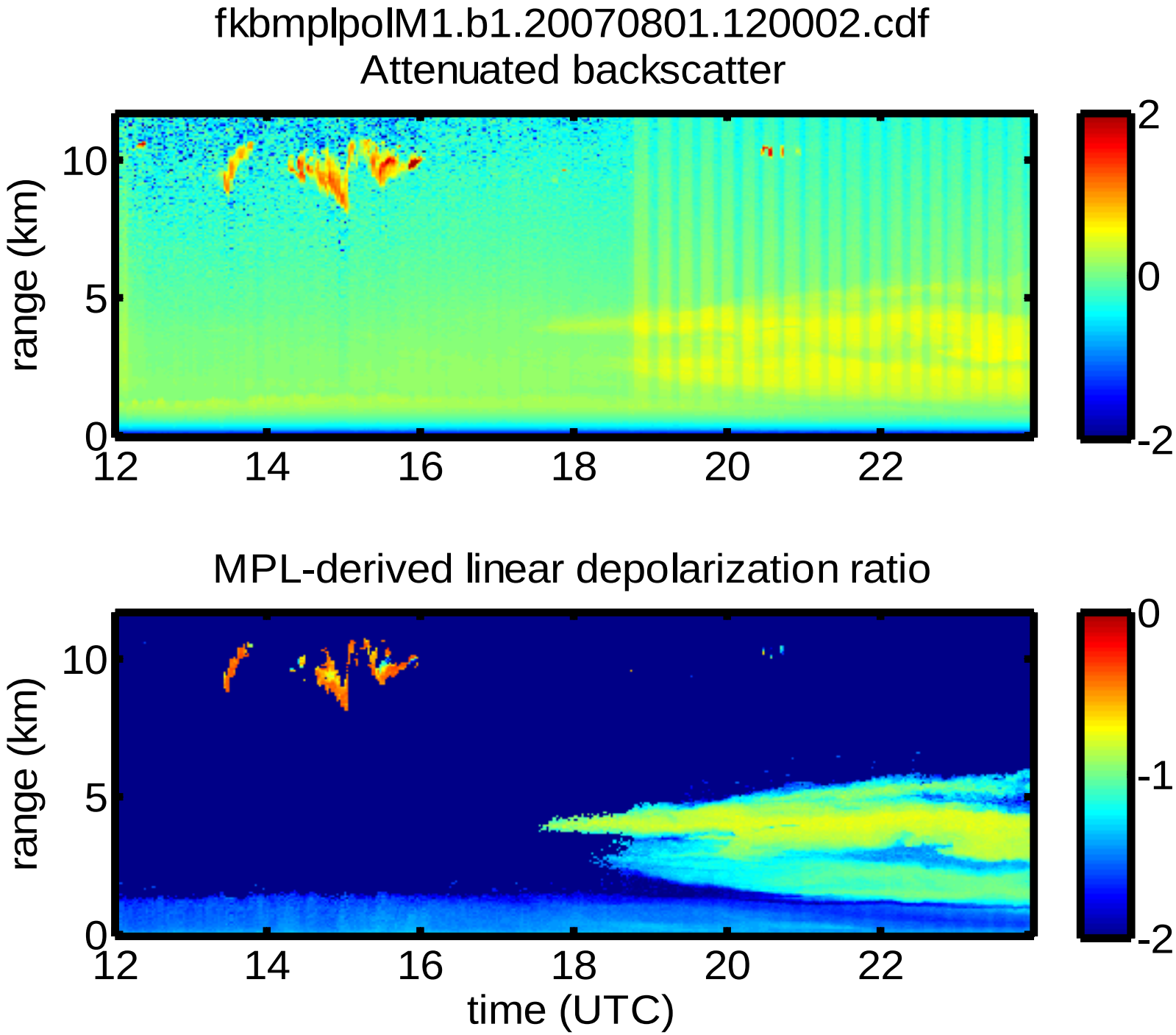
2
1
14
16
18
20
22
2
0
-2
MPL-derived linear depolarization ratio
range (km)
3
2
1
14
16
18
20
22
time (UTC)
0
-1
-2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Attenuated backscatter
range (km)
10
5
0
12
14
16
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22
2
0
-2
MPL-derived linear depolarization ratio
range (km)
10
5
0
12
14
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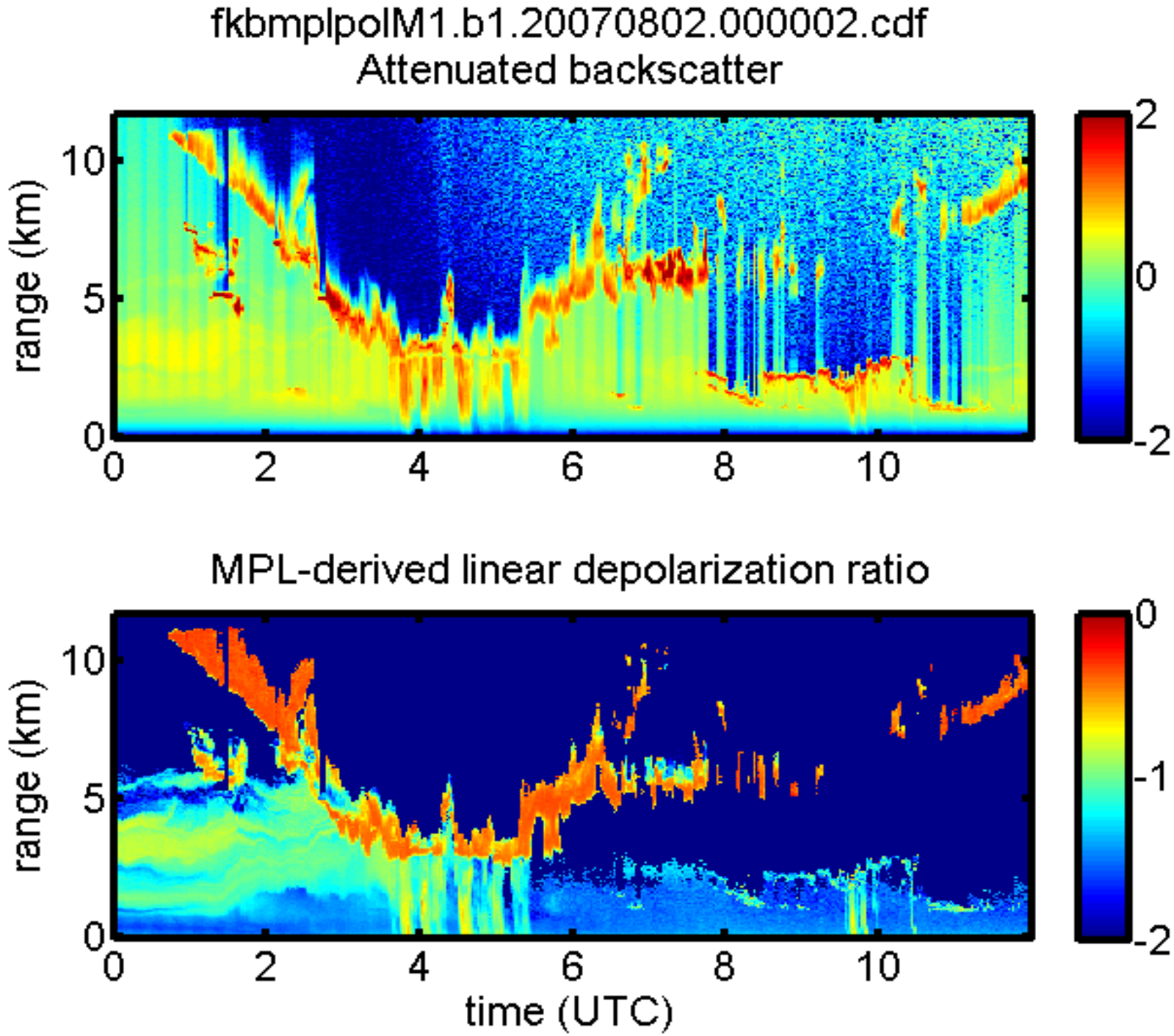
18
20
22
time (UTC)
0
-1
-2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Attenuated backscatter
range (km)
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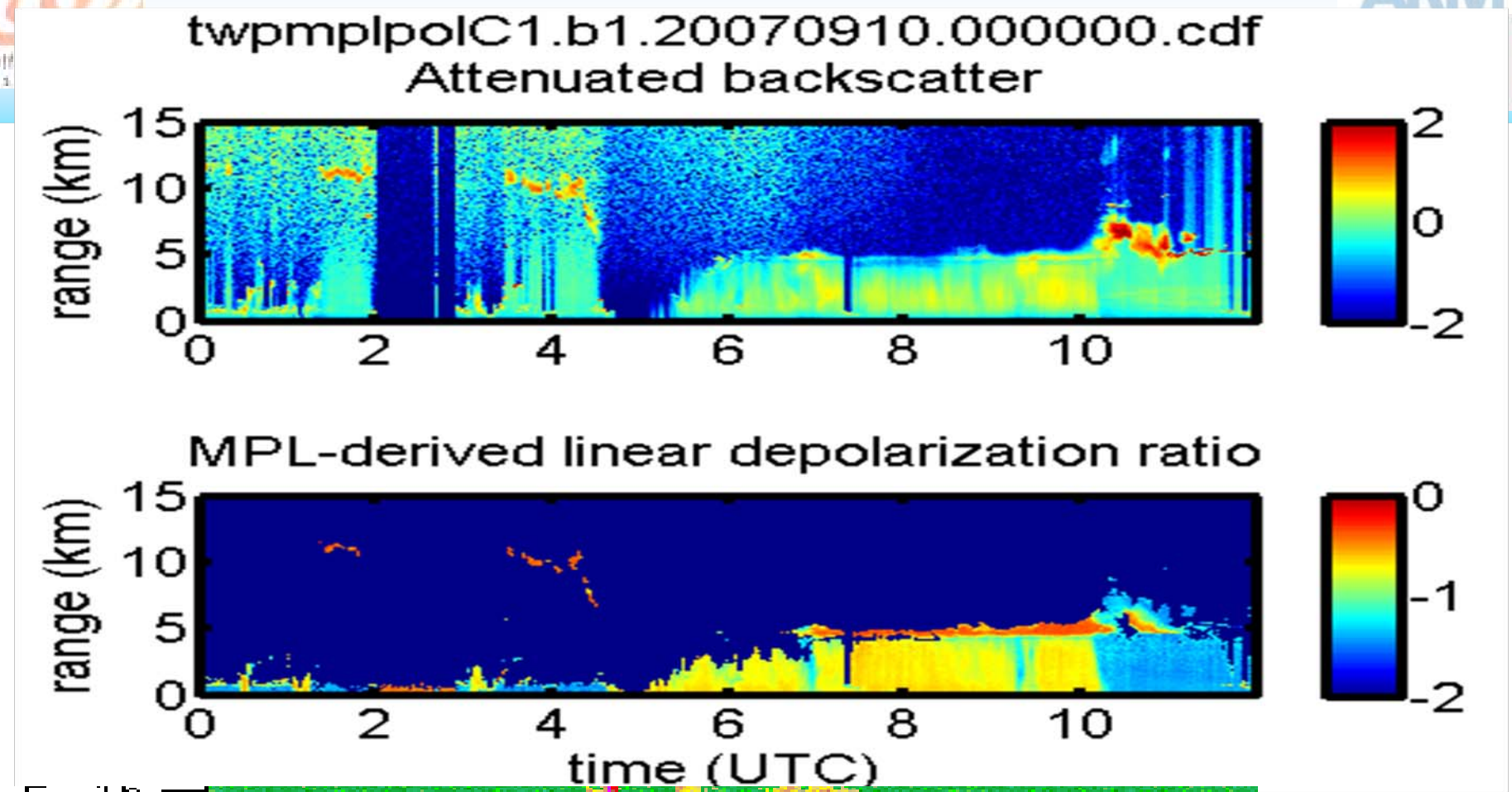
5
0
0
2
4
6
8
10
2
0
-2
MPL-derived linear depolarization ratio
range (km)
10
5
0
0
2
4
6
8
10
time (UTC)
0
-1
-2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Attenuated backscatter
range (km)
15
10
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0
0
2
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2
0
-2
MPL-derived linear depolarization ratio
range (km)
15
10
5
0
0
2
4
6
8
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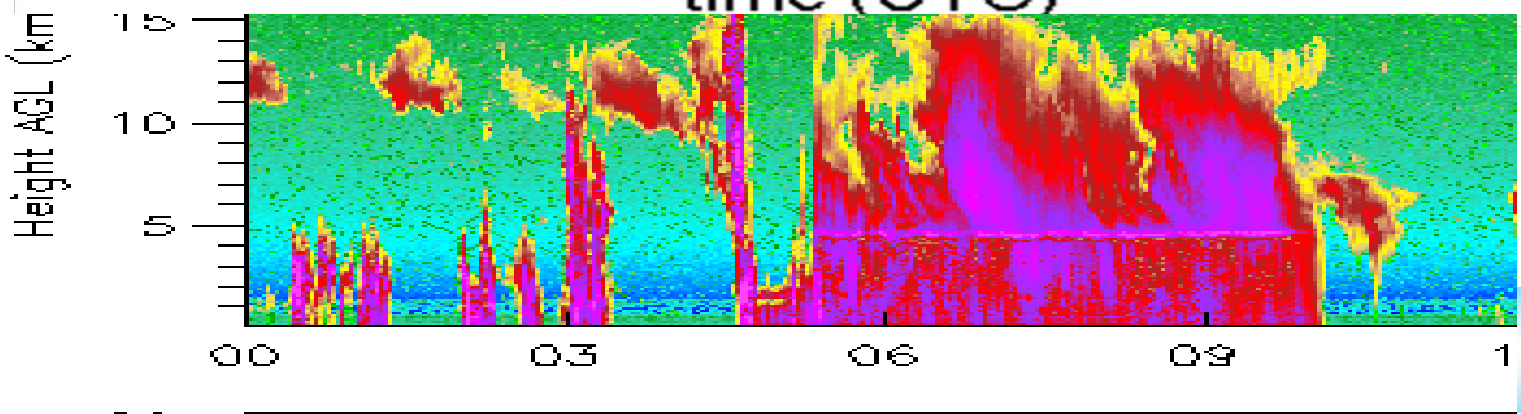
0
-1
-2
time (UTC)


Height AGL (km
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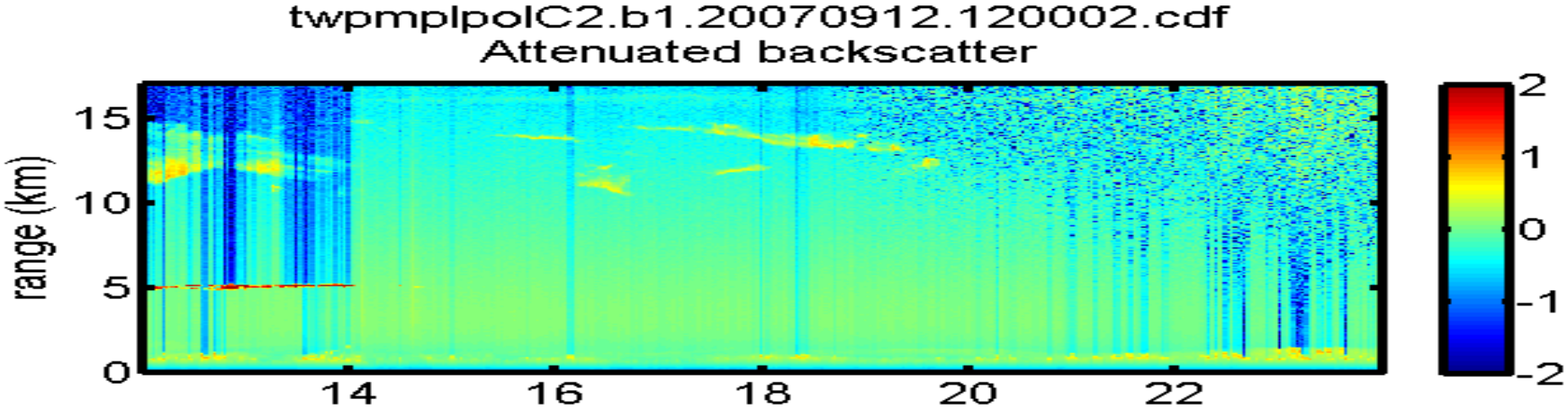
10
5
00
03
06
09
1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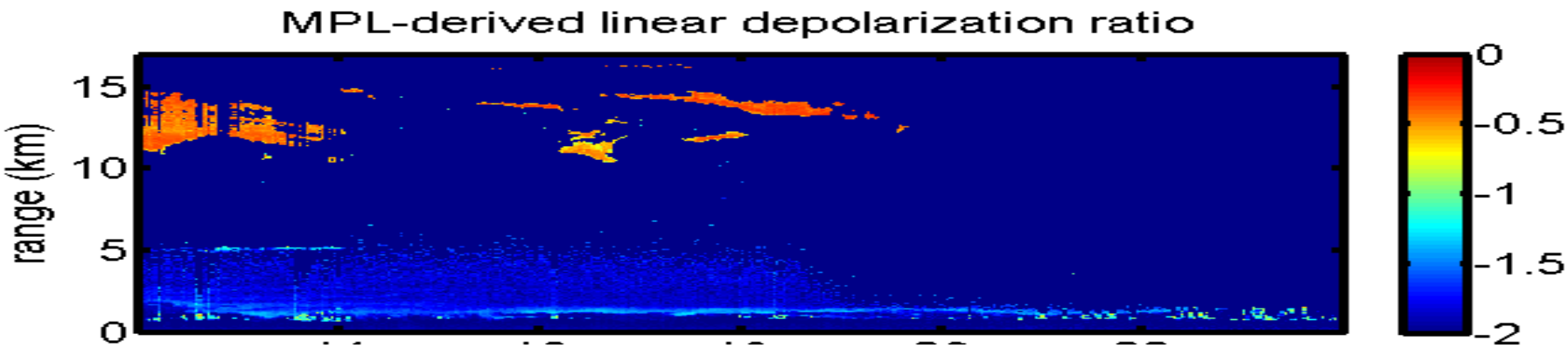
Attenuated backscatter
range (km)
15
10
5
0
14
16
18
20
22
2
1
0
-1
-2


MPL-derived linear depolarization ratio
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-0.5
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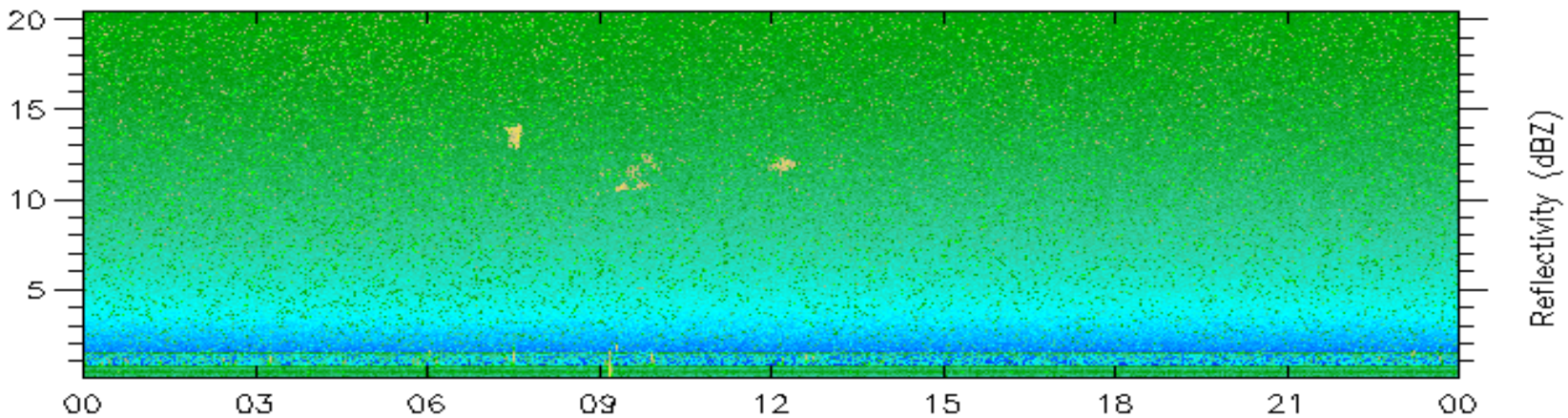
-2


20
15
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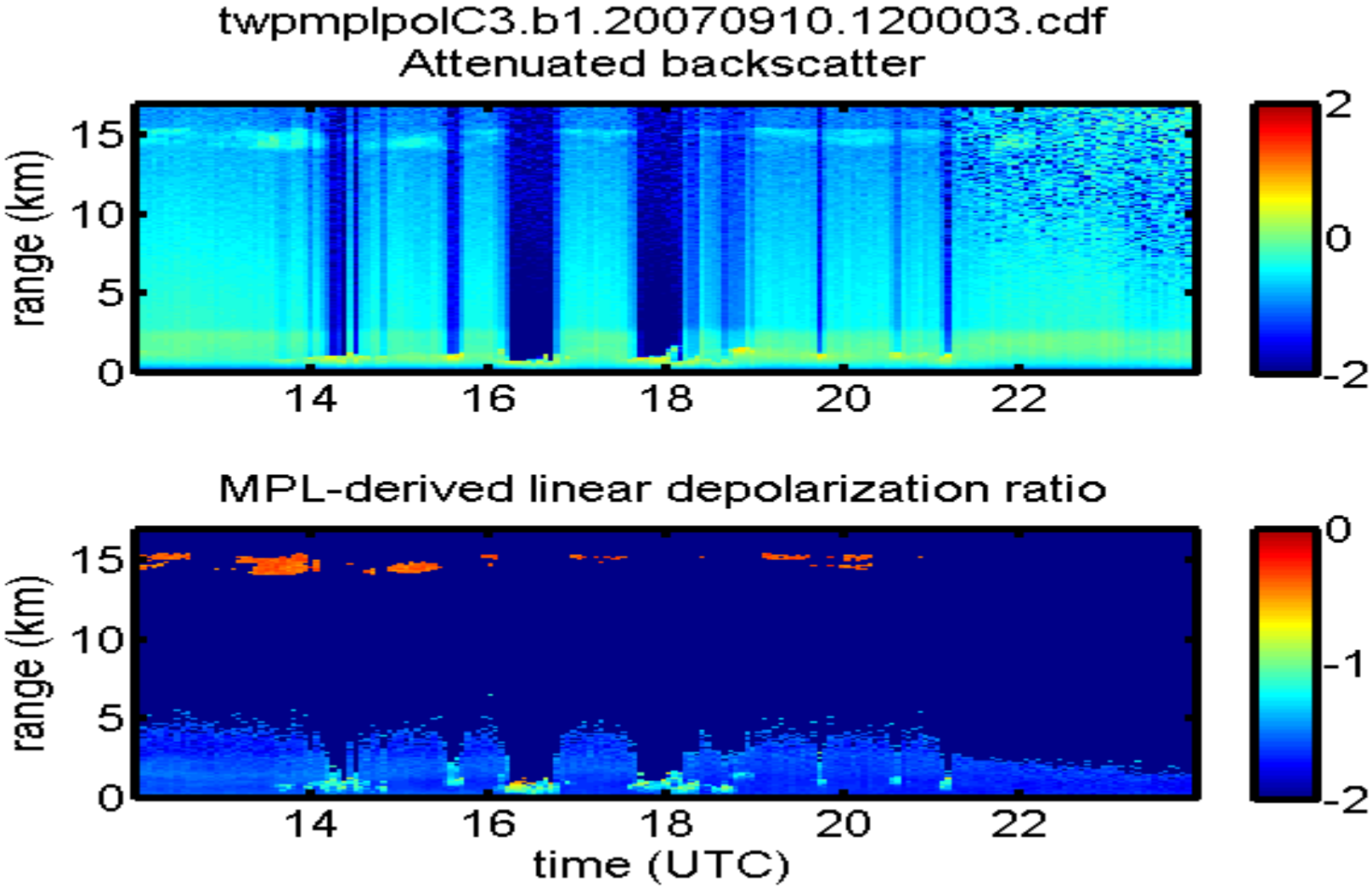
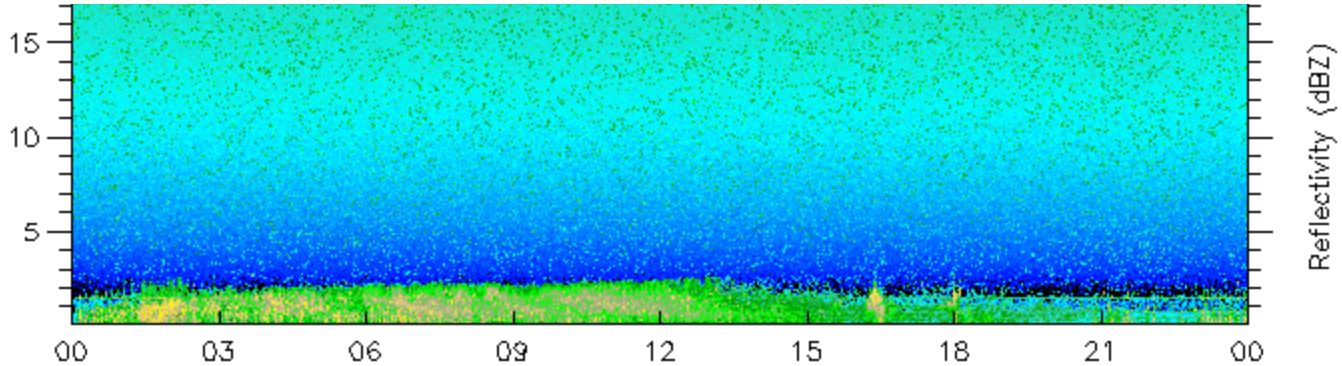
12
15
18
21
00
Reflectivity (dBZ)


twpmplpolC3.b1.20070910.120003.cdf
Attenuated backscatter
range (km)
15
10
5
0
14
16
18
20
22
2
0
-2
MPL-derived linear depolarization ratio
range (km)
15
10
5
0
14
16
18
20
22
time (UTC)
0
-1
-2


15
10
5
00
03
06
09
12
15
18
21
00
Reflectivity (dBZ)

Summary

- Demonstrable sensitivity to depolarization by cloud and aerosol.
- Although a “hybrid” measurement, connections to common depol ratios are clear
- Data available at all sites 2006/2007
- Detailed comparisons possible at MPACE with MPL, HSRL, and PDL
- Long-term comparisons at SGP with RL in progress