Comparison of CALIPSO, GLAS, and LITE CFLOS Statistics for Use In DWL Mission Design and OSSEs

S. Greco and D. Emmitt

WG SBLW

Wintergreen, VA

June 17, 2009

CALIPSO/LITE ROSES07 study

The ROSES07study is using both LITE and CALIPSO data to address the following four major issues:

- **Cloud free line-of-sight (CFLOS) statistics for laser beam footprints (with particular interest in contiguous laser shot integration intervals),**
- Global aerosol backscatter distributions with particular interest in their correlation with cloud and atmospheric dynamics,
- Conversion of observations at CALIPSO wavelengths to those pertinent to GWOS, the hybrid wind lidar (.355 and 2.01 microns); validation of aerosol backscatter distributions being used in NASA/NOAA OSSEs.
- Instrument trade studies relevant to the GWOS instrument concept using an existing Doppler Lidar Simulation Model

Overview

- **Develop a state-of-the-art set of *cloud free line-of-sight (CFLOS) statistics and atmospheric optical properties for space-based Doppler Wind Lidar (DWL)* design using both LITE and CALIPSO data and use the Doppler Lidar Simulation Model (DLSM) to conduct basic trade studies that relate** directly to laser design and scanning options.
- Effort is focused upon issues that are unique to the *hybrid (coherent and direct detection combined) Doppler Wind Lidar* being considered for the first USA mission. In particular, deriving 2 micron coherent performance from .532/1.06 µm CALIPSO data is non-trivial and is being modeled by Bowdle (UAH).
- Our revisit to the LITE data is in recognition of the fact that *LITE was the most powerful backscatter lidar ever flown* in space. Since the weak aerosol distributions are being investigated, the LITE data appears to be most useful.
- **Simpson Weather Associates' (SWA) study of the CFLOS statistics from the ICESat GLAS (Geosciences Laser Altimeter System) data sets provides the motivation and methodology behind this work as well as data for comparison**

Planning and Strategy

- **All Calipso Level 2 cloud products (333m, 1km and 5km) would be investigated but the focus would be on the 1 km product**
  - **Cloud top, Cloud base, Number of Layers**
  - **Surface elevation/detection**
- August 2007 was selected as the case study
- Data obtained from the NASA Langley Atmospheric Science Data center
- Comparison with existing results from LITE and GLAS

Laser and Data Features

- LITE (September 1994)
  - **532**/1064 nm
  - 530 mJ@532; 470 mJ@1064
  - 740m horizontal; 15 m vertical
- CALIPSO (August 2007)
  - **532**/1064 nm
  - 110 mJ per channel
  - 333m horizontal;30-60m vertical
- GLAS (November 2003)
  - **532**/1064 nm
  - 35 mJ @532; 75 mJ @1064
  - 170m horizontal; ~ 70 m vertical

Previous Results: LITE CFLOS study

The general conclusions of the LITE data analyses of cloud porosity for lasers were that:

- The 532nm beam provided **a ground return more often (~60 - 65%)** than the current cloud climatologies based upon passive imagers suggested (~30-40%).
- **More than 50% of the time that the lidar beam intercepted a cloud it also provided a ground return**. In other words the porosity of the clouds to the LITE beams was on the order of 50%.
- **Study by Berthier et al. found global cloud cover to be ~ 70%**

Previous Results: GLAS

- **SWA found that 70 - 80% of the GLAS lidar samples involved some return from clouds** (assumed that "no cloud/no ground returns" intercepted thick layers of optically thin clouds). Other work by BERTHIER also found global cloud cover between 65-80%

- **75 - 80% of the GLAS lidar samples detected the earth's surface** (adjusted for smooth water returns)

- When clouds were present, 25 – 40% of the time at least two layers were detected.

(http://esto.nasa.gov/adv_planning_studies_archive.html).

CALIPSO RESULTS
(for August 8 – 14)

Shot Resolution/Distribution

- CALIPSO
  - 333 m – single shot
  - ***1 km - (3 shots)***
  - 5 km – (15 shots)

- GLAS
  - Full resolution (170 m)
  - ***High resolutions (8 shots over 1.36 km)***
  - Medium resolution (40 shots over 6.8 km)

CALIPSO: 333m vs 1km vs 5km product

Condition	333 m	1 km	5km
Cloud	49.5 (49.1)	71.0 (73.2) (70.0)	81.2
No Cloud	50.5	29.0	18.8
Hit Ground	NA	50.1(45.0/ 59.0) (60.0-65.0)	53.5
No Ground	NA	49.9	46.5

CALIPSO: 333m vs 1km vs 5km product

.

Condition	333 m	1 km	5km
No Cloud	50.5	29.0	18.8
1 cloud Layer	37.3 (75.5) (70.0)	50.0 (70.4) (70.0)	33.1 (40.8)
2 cloud layers	8.4 (17.1)	16.8 (23.7)	19.9 (24.5)
>2 cloud layers	3.7 (7.5)	4.2 (5.9)	28.2 (34.7) (25.0)

Numbers in parentheses reflect cases where there were clouds.

CALIPSO: 333m vs 1km vs 5km product

Condition	333 m	1 km	5km
Cloud and Ground		22.8	35.6
No Cloud and Ground		27.3	17.9
Cloud and No Ground		48.2	45.6
No Cloud and No Ground		1.7	0.9
Percent of cloud that hit ground		32.1 (37.0-50.0) (34.0-49.0)	43.8

CALIPSO: 1 KM Product

Condition	*ALL*	*Day*	*Night*
Cloud	69.6	71.1	67.9
No Cloud	30.4	28.9	32.1
Hit Ground	55.1 (60-65, 45.0, 59.0)	48.9	62.1
No Ground	44.9	51.1	37.9
Cloud and Ground	25.6	21.3	30.3
No Cloud & Ground	29.6	27.6	31.9
Cloud & NoG	44.1	49.8	37.6
No Cloud &NoG	0.8	1.3	0.3

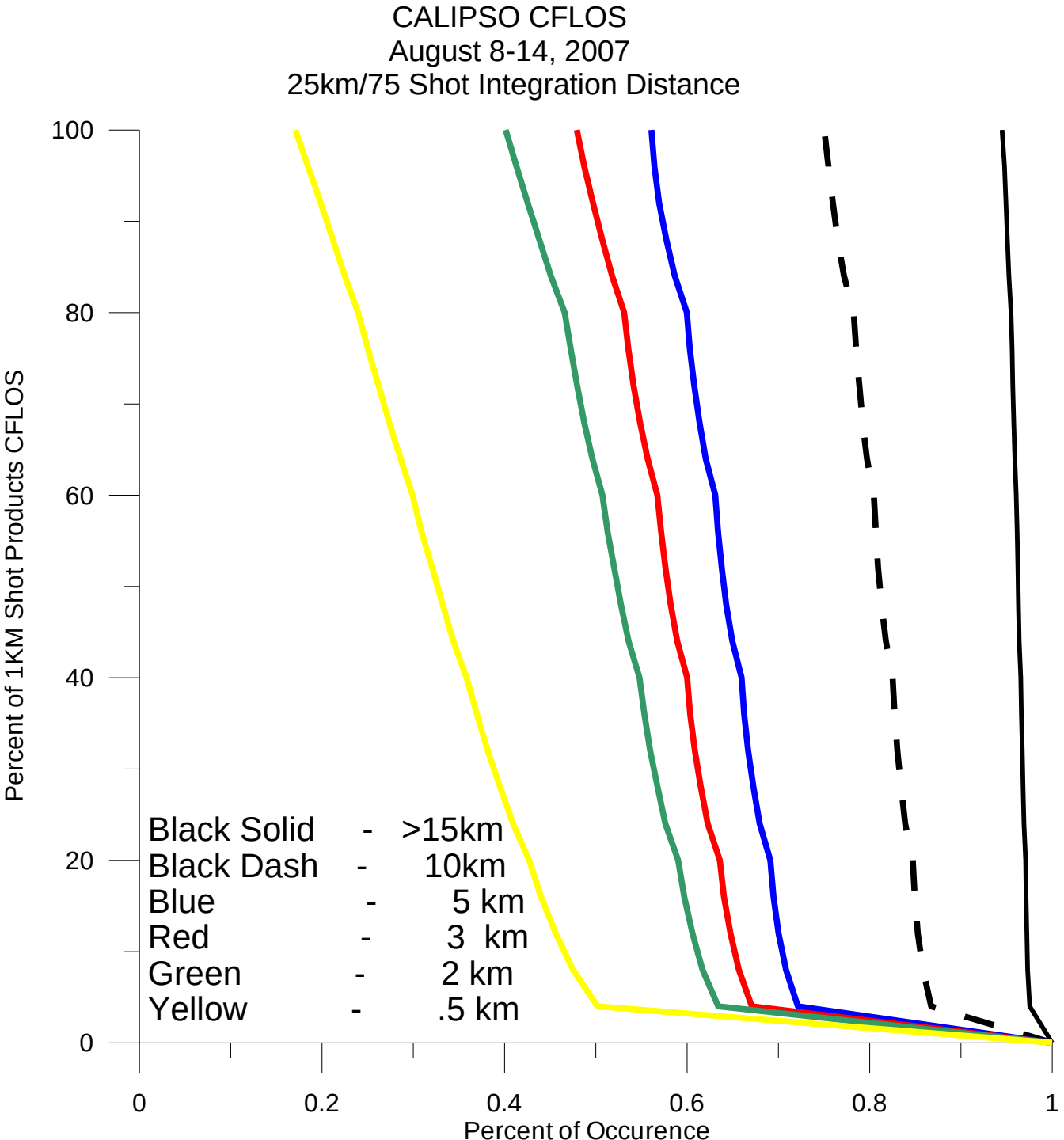
Condition	ALL	Water	Land	Ice
Cloud	69.6 (49.1)	76.7	57.5 (47.3)	54.9
No Cloud	30.4	23.3	42.5	45.1
Hit Ground	55.1 (44.7)	47.9	61.2 (57.1)	83.8
No Ground	44.9	52.1	38.8	16.2
Cloud and Ground	25.6	25.6	19.3	38.9
No Cloud and Ground	29.6	22.3	41.9	44.9
Cloud &No Ground	44.1	51.1	38.3	16.0
No Cloud & No Ground	0.8	1.0	0.6	0.1

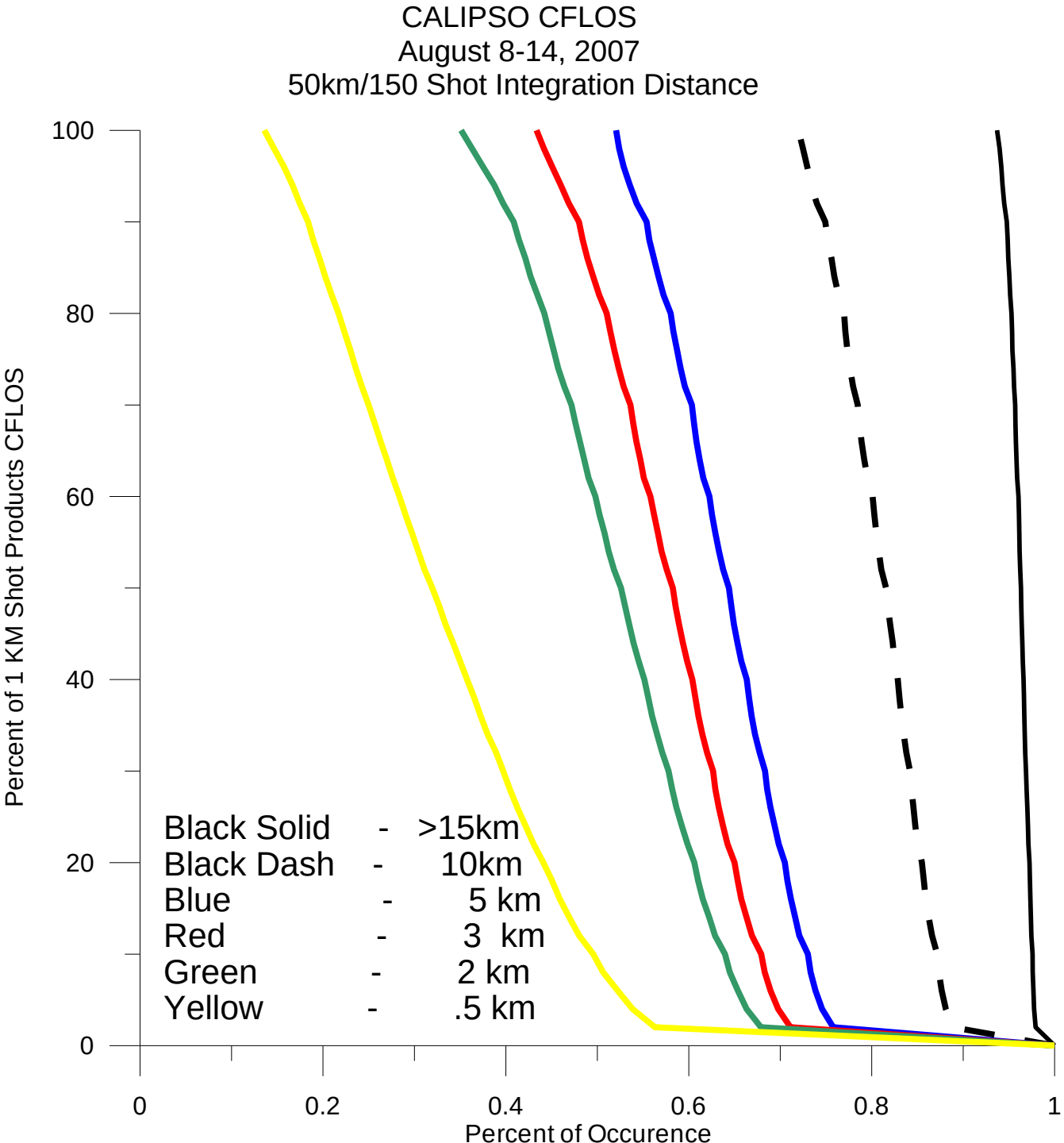
CFLOS Statistics

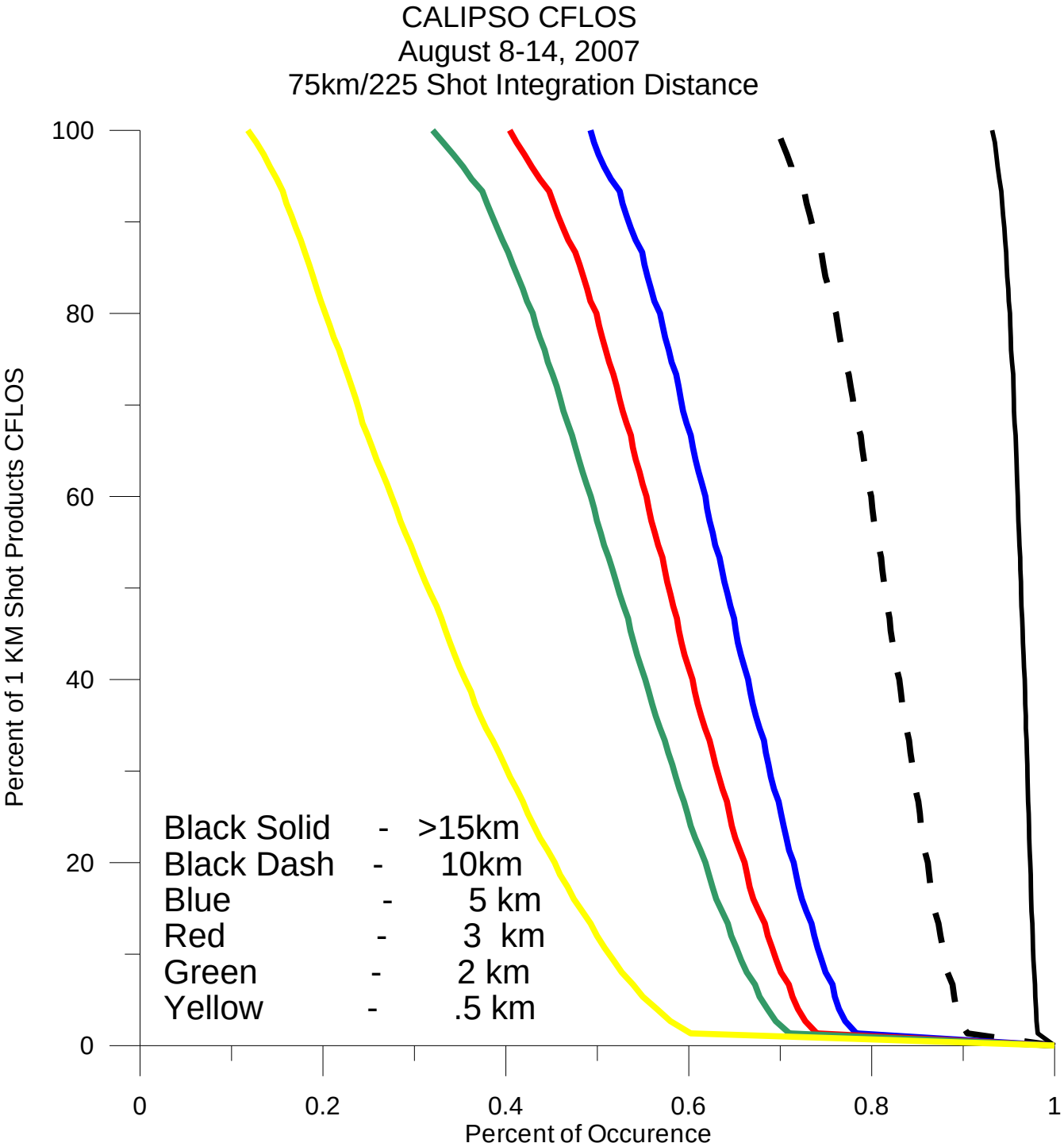
- Cloud-Free-Line-Of-Sight (CFLOS)
  - Does the lidar shot (product) make it down to a certain level without any cloud detection?
- Pass Through
  - Is there a ground return or cloud returns below a certain level?
- Integration Distances for 1 km product
  - 25 KM (25 products/75 shots)
  - 50 KM (50 products/150 shots)
  - 75 KM (75 products/225 shots)

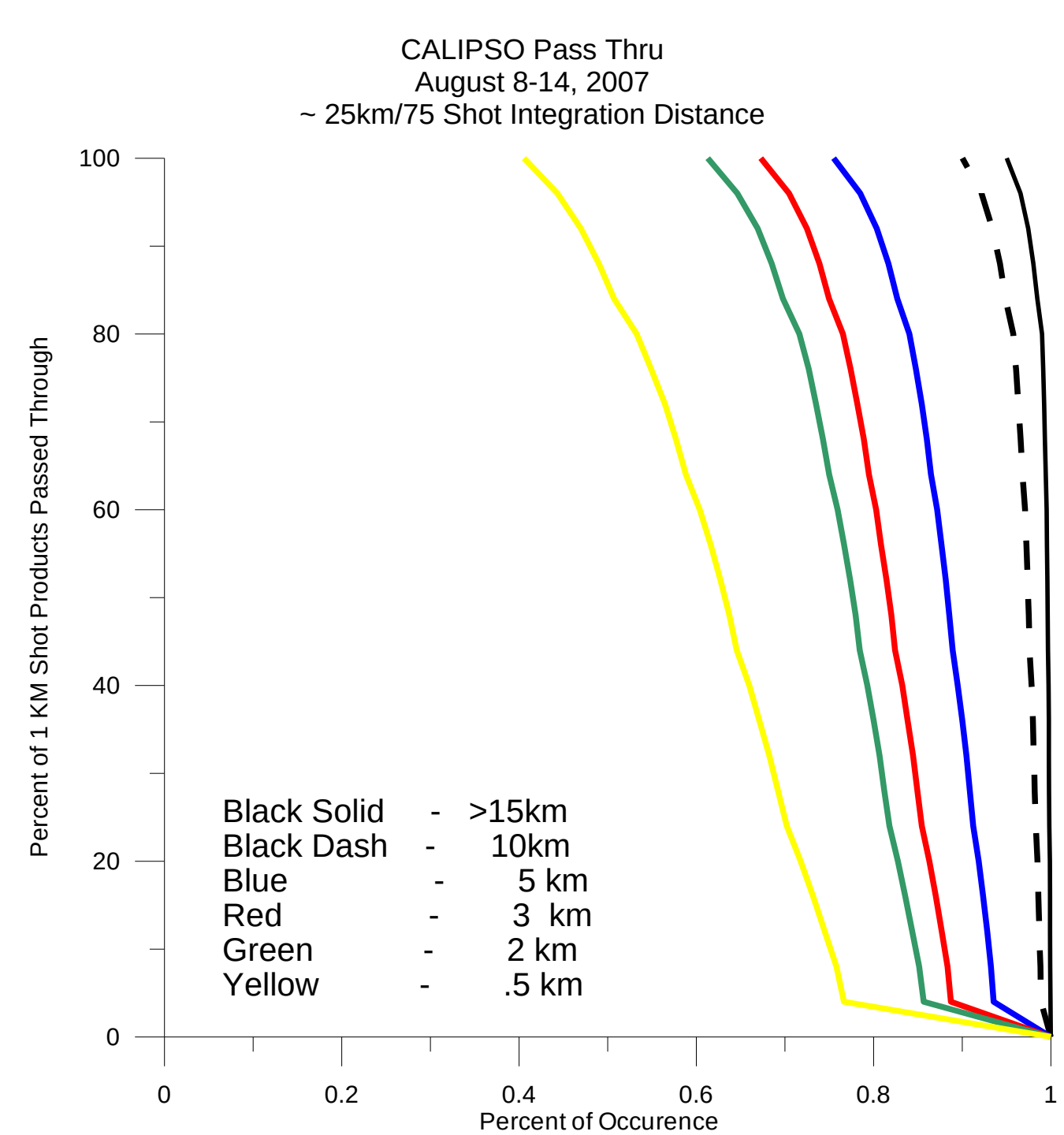
CFLOS Statistics –Why?

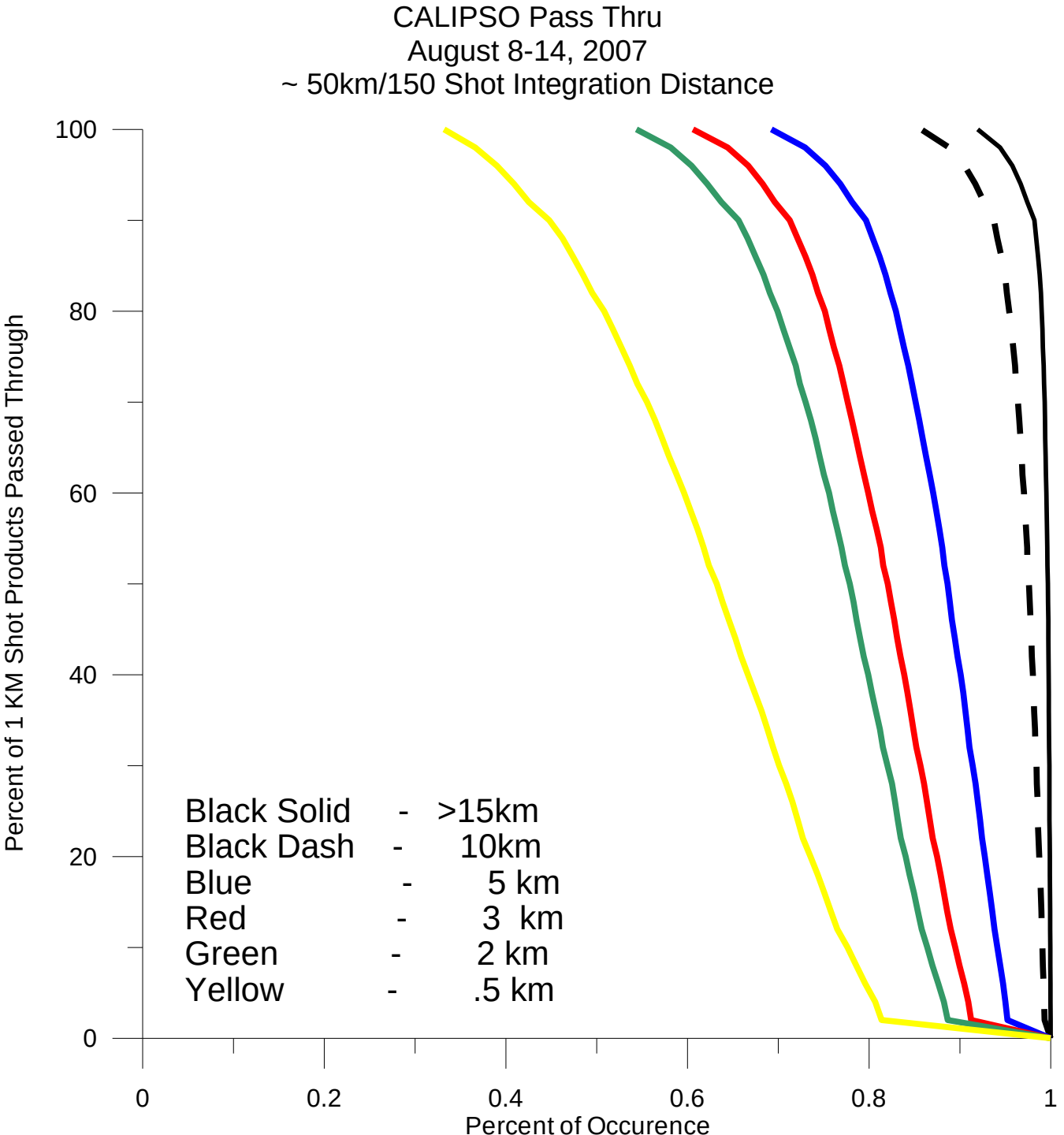
- Trade studies on lidar technology or sampling strategies
  - Efficiency needed
  - Integration length
  - Efficiency vs EAP vs Integration length
- How many consecutive shots have either a CFLOS or, despite clouds, made it to a lower level?

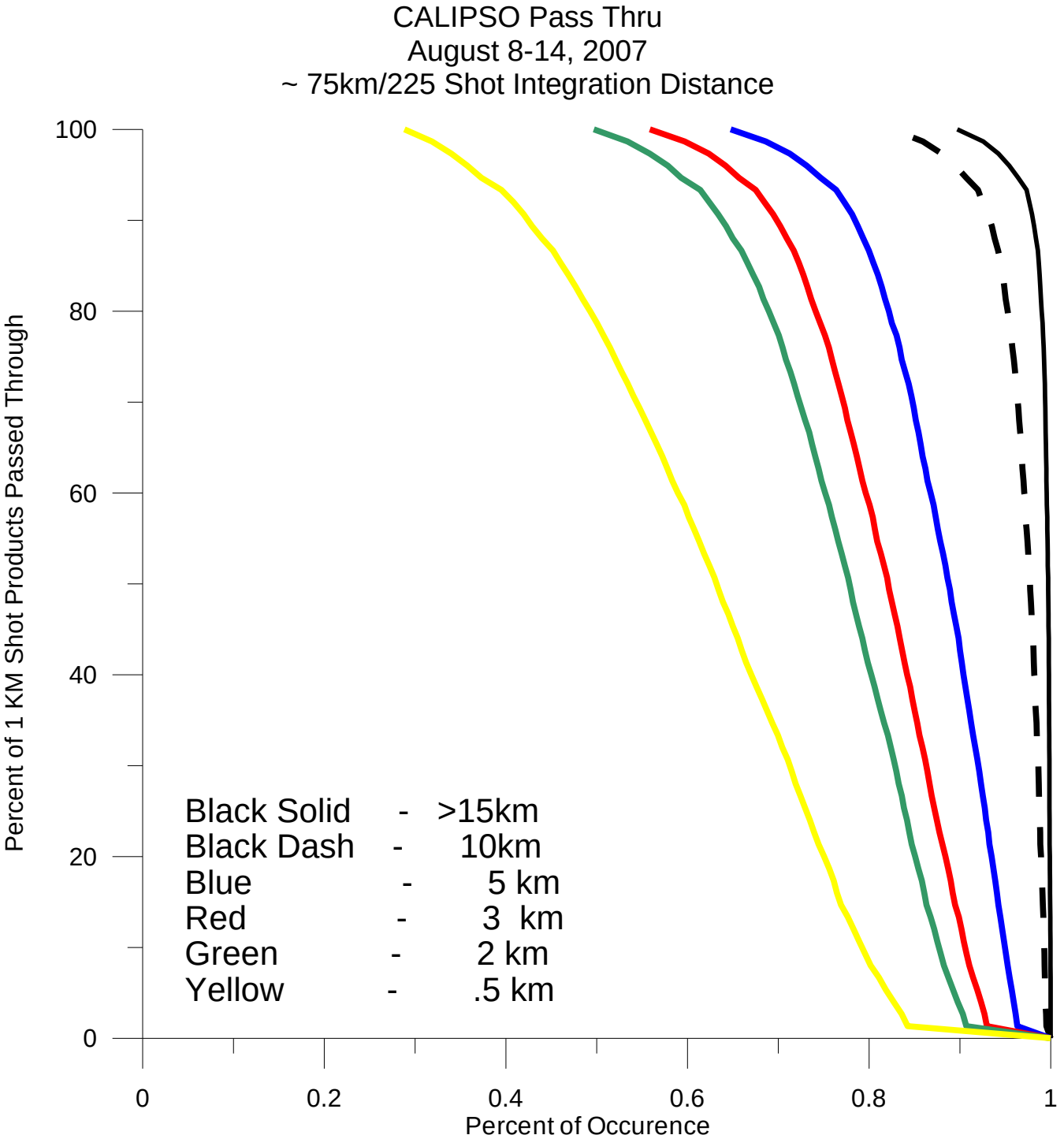

CALIPSO CFLOS
August 8-14, 2007
25km/75 Shot Integration Distance
Percent of 1KM Shot Products CFLOS
100
80
60
40
20
0
0
0.2
0.4
0.6
0.8
1
Percent of Occurence
Black Solid - >15km
Black Dash - 10km
Blue - 5 km
Red - 3 km
Green - 2 km
Yellow - .5 km


CALIPSO CFLOS
August 8-14, 2007
50km/150 Shot Integration Distance
Percent of 1 KM Shot Products CFLOS
100
80
60
40
20
0
0
0.2
0.4
0.6
0.8
1
Percent of Occurence
Black Solid - >15km
Black Dash - 10km
Blue - 5 km
Red - 3 km
Green - 2 km
Yellow - .5 km


CALIPSO CFLOS
August 8-14, 2007
75km/225 Shot Integration Distance
Percent of 1 KM Shot Products CFLOS
100
80
60
40
20
0
0
0.2
0.4
0.6
0.8
1
Percent of Occurence
Black Solid - >15km
Black Dash - 10km
Blue - 5 km
Red - 3 km
Green - 2 km
Yellow - .5 km


CALIPSO Pass Thru
August 8-14, 2007
~ 25km/75 Shot Integration Distance
Percent of 1 KM Shot Products Passed Through
100
80
60
40
20
0
0
0.2
0.4
0.6
0.8
1
Percent of Occurence
Black Solid - >15km
Black Dash - 10km
Blue - 5 km
Red - 3 km
Green - 2 km
Yellow - .5 km


CALIPSO Pass Thru
August 8-14, 2007
~ 50km/150 Shot Integration Distance
Percent of 1 KM Shot Products Passed Through
100
80
60
40
20
0
0
0.2
0.4
0.6
0.8
1
Percent of Occurence
Black Solid - >15km
Black Dash - 10km
Blue - 5 km
Red - 3 km
Green - 2 km
Yellow - .5 km


CALIPSO Pass Thru
August 8-14, 2007
~ 75km/225 Shot Integration Distance
Percent of 1 KM Shot Products Passed Through
100
80
60
40
20
0
0
0.2
0.4
0.6
0.8
1
Percent of Occurence
Black Solid - >15km
Black Dash - 10km
Blue - 5 km
Red - 3 km
Green - 2 km
Yellow - .5 km

100% Pass Through Efficiency for 50 KM Integration Length.

Altitude (m)	Calipso 333m	Calipso 1km	Calipso 5km
> 15000		87.7	90.1
10000		82.7	87.8
5000		63.3	74.9
3000		54.5	65.9
2000		48.6	60.7
500		28.8	42.7

80% Pass Through Efficiency for 50 KM Integration Length.

Altitude (m)	Calipso 333m	Calipso 1km	Calipso 5km
> 15000		97.1	93.7
10000		93.9	92.5
5000		78.3	82.5
3000		70.7	74.1
2000		65.4	69.7
500		47.3	54.4

100% CFLOS Efficiency for 50 KM Integration Length.

Altitude (m)	Calipso 333m	Calipso 1km	Calipso 5km
> 15000	100.0	87.8	91.2
10000	100.0	75.0	65.6
5000	68.8	47.9	42.3
3000	59.5	38.8	36.3
2000	48.1	29.9	28.0
500	21.1	9.7	9.7

80% CFLOS Efficiency for 50 KM Integration Length.

Altitude (m)	Calipso 333m	Calipso 1km	Calipso 5km
> 15000	100.0	99.1	91.7
10000	100.0	84.4	71.6
5000	86.5	61.3	48.9
3000	78.5	55.6	44.8
2000	72.8	50.4	39.0
500	56.2	31.9	18.5

Effects of Integration Distance

Effect of Integration Distance -100% Pass Through Efficiency

Altitude (m)	75 km	50 km	25 km
> 15000	89.7	92.0	95.0
10000	82.6	85.7	90.0
5000	64.8	69.2	75.5
3000	55.9	60.6	67.3
2000	49.7	54.4	61.3
300	28.8	33.2	40.6

Effect of Integration Distance -50% Pass Through Efficiency

Altitude (m)	75 km	50 km	25 km
> 15000	99.7	99.7	99.6
10000	97.7	97.6	97.4
5000	88.8	88.7	88.3
3000	82.1	82.1	81.7
2000	77.8	77.9	77.7
500	63.2	63.2	63.2

Effect of Integration Distance -100% CFLOS Efficiency

Altitude (m)	75 km	50 km	25 km
> 15000	93.2	93.8	94.5
10000	69.7	72.0	75.0
5000	49.3	52.1	56.1
3000	40.4	43.4	47.9
2000	32.0	35.1	40.1
500	11.8	13.6	17.1

Effect of Integration Distance - 50% CFLOS Efficiency

Altitude (m)	75 km	50 km	25 km
> 15000	96.3	96.3	96.3
10000	81.4	81.6	81.1
5000	64.1	64.4	64.1
3000	57.8	58.3	57.9
2000	52.2	52.6	52.4
500	31.5	32.0	32.6

CALIPSO and GLAS Comparisons

Comparison with GLAS: 100% CFLOS Efficiency at 50 KM

Altitude (m)	GLAS Low (532)	GLAS Mid (532)	GLAS High	Calipso 1km
> 15000	97.4	97.4	95.9	93.8
30000	85.6	84.6	78.7	72.0
5000	66.3	63.7	54.3	52.1
3000	59.1	55.9	44.8	43.4
2000	50.8	47.2	32.5	35.1
500	31.6	25.6	13.4	13.6

Comparison with GLAS: 50% CFLOS Efficiency at 50 KM

Altitude (m)	GLAS Low (532)	GLAS Mid (532)	GLAS High	Calipso 1km
> 15000	98.5	98.7	98.4	96.3
30000	90.4	89.6	86.6	81.6
5000	74.8	72.3	65.3	64.4
3000	68.4	64.7	55.6	58.3
2000	61.9	57.3	47.4	52.6
500	44.8	36.2	22.2	32.0

Tropical vs Mid-Latitude (1 KM Product)

Condition	ALL	Tropical	Mid-lat	Polar
Cloud	69.6	66.1	72.5	70.2
No Cloud	30.4	33.9	27.5	29.8
Hit Ground	55.1	60.1	47.5	58.0
No Ground	44.9	39.9	52.5	42.0
Cloud and Ground	25.6	27.3	21.1	28.4
No Cloud and Ground	29.6	32.8	26.4	29.6
Cloud & NoG	44.1	38.8	51.4	41.8
No Cloud & No Ground	0.8	1.1	1.1	0.2

100% CFLOS Efficiency for 50 KM Integration Length.

Altitude (m)	1 km ALL	1 km TROP	1 km MID	1 km POL
> 15000	93.8	85.3	98.7	97.5
10000	72.0	62.0	73.5	81.8
5000	52.1	53.8	50.3	50.5
3000	43.4	44.8	42.1	41.6
2000	35.1	35.0	33.8	35.6
500	13.6	9.3	10.9	21.6

80% CFLOS Efficiency for 50 KM Integration Length.

Altitude (m)	1 km ALL	1 km TROP	1 km MID	1 km POL
> 15000	95.3	88.4	99.1	98.6
10000	77.0	67.2	78.8	86.1
5000	58.0	59.4	56.2	57.9
3000	51.0	54.1	49.4	48.5
2000	44.2	47.1	42.5	42.4
500	21.7	18.4	19.0	28.6

Continuing Work

- Utilize the latest data release to extend statistics to entire month (August 2007) and for all three cloud products (333 m, 1 km, 5 km)
- Currently examining CALIPSO overpasses of TPARC/TCS08 cases where P3DWL was scanning both up and down.
- Phenomological/Synoptic Studies
- Backscatter portion of study is in progress. Exploring ways to determine distribution of “background” vs “enhanced” aerosol regions.