The cloud base is just the beginning: Advanced applications of Vaisala ceilometers

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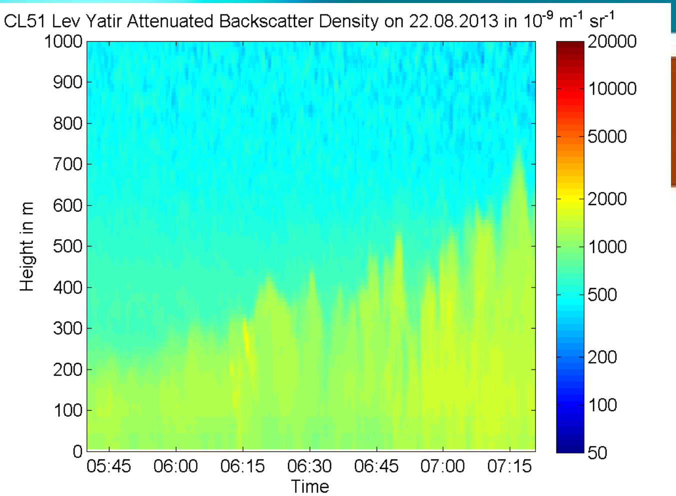

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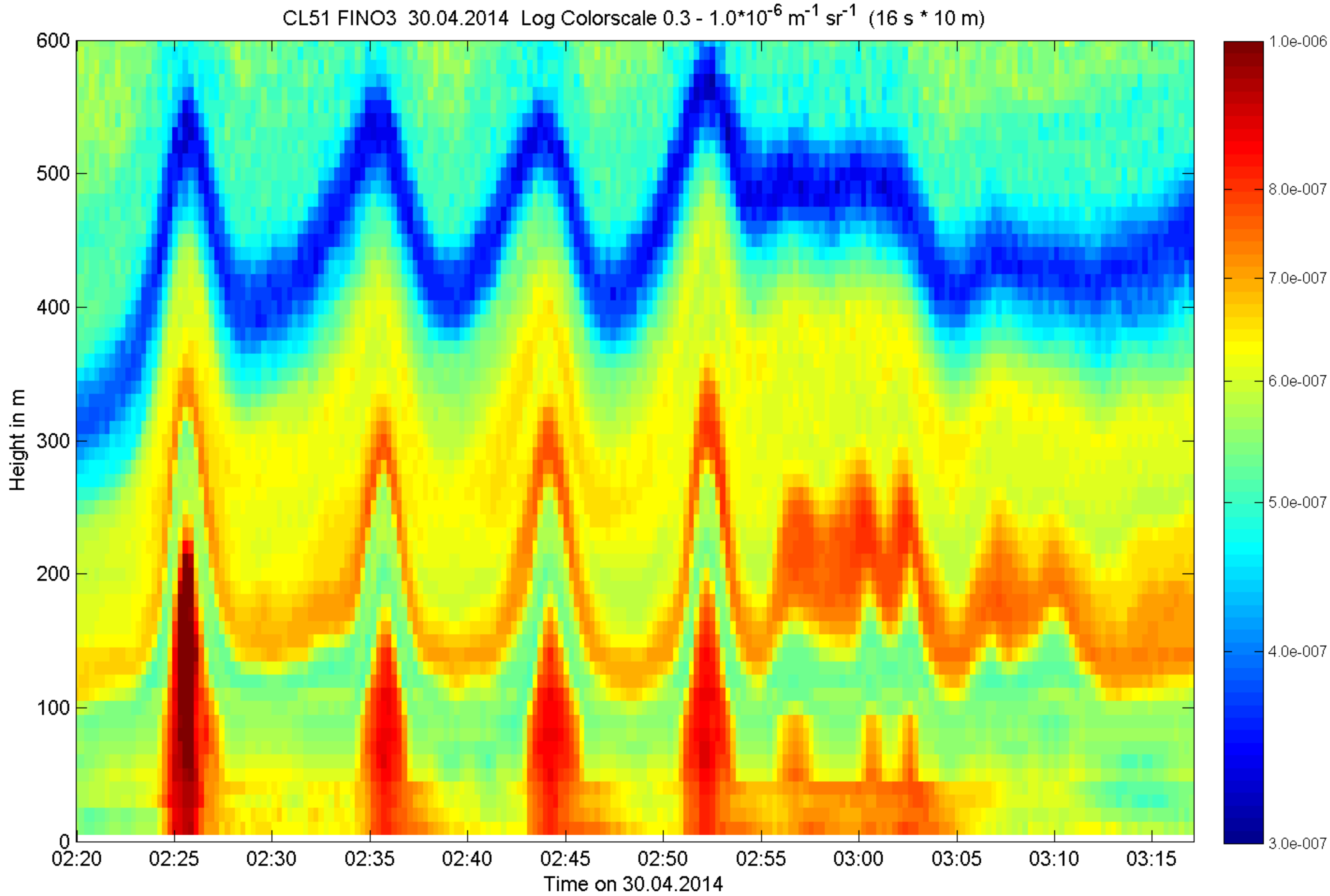
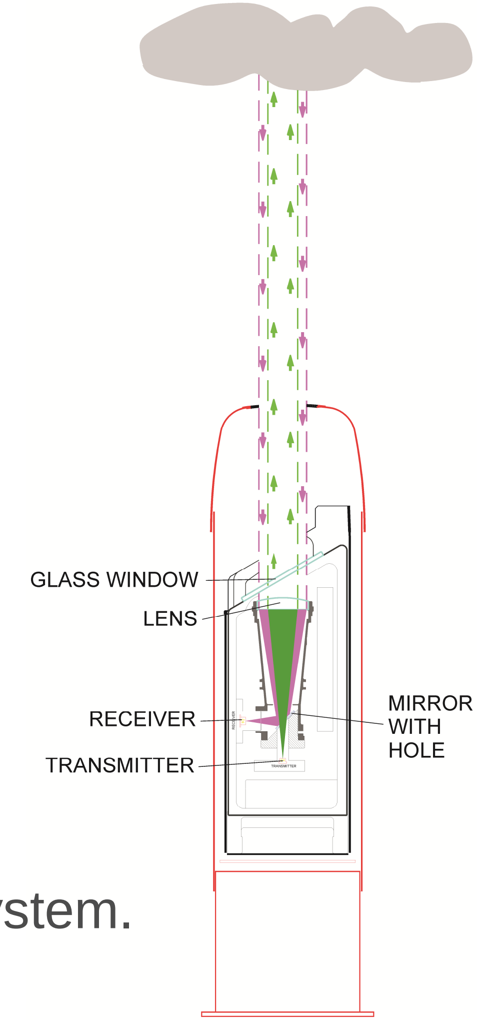


CL51 FINO3 30.04.2014 Log Colorscale 0.3 - 1.0*10^{-6} m^{-1} sr^{-1} (16 s * 10 m)
Height in m
0
100
200
300
400
500
600
02:20
02:25
02:30
02:35
02:40
02:45
02:50
02:55
03:00
03:05
03:10
03:15
Time on 30.04.2014
1.0e-006
8.0e-007
7.0e-007
6.0e-007
5.0e-007
4.0e-007
3.0e-007

Contents

- Introduction to Vaisala ceilometers
- Ceilometer calibration
- Monitoring particle emissions
- Elevated dust layers
- Extinction profiles
- Mixing layer height determination
- High resolution profiling

Single lens ceilometer Vaisala CL31



- Simple and reliable instrument design.
- Sufficient overlap already 10 m above the system.
- More than 4000 units in operation.

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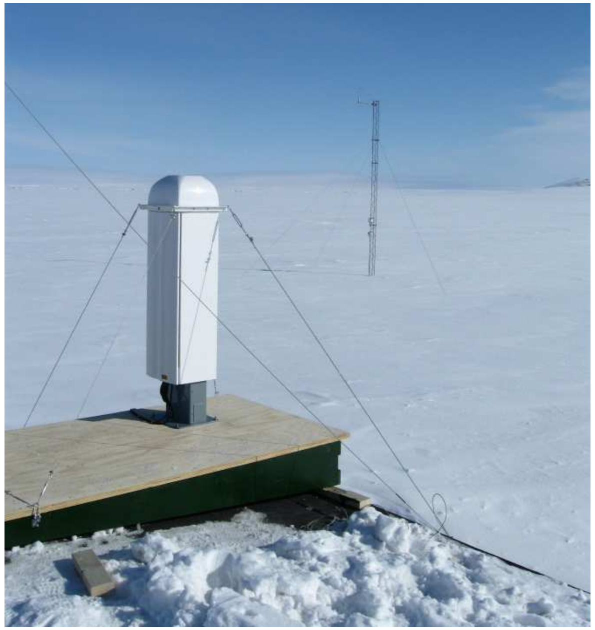
Single lens ceilometer Vaisala CL51

Lev-Yatir, Israel
operated by KIT/IMK-IFU

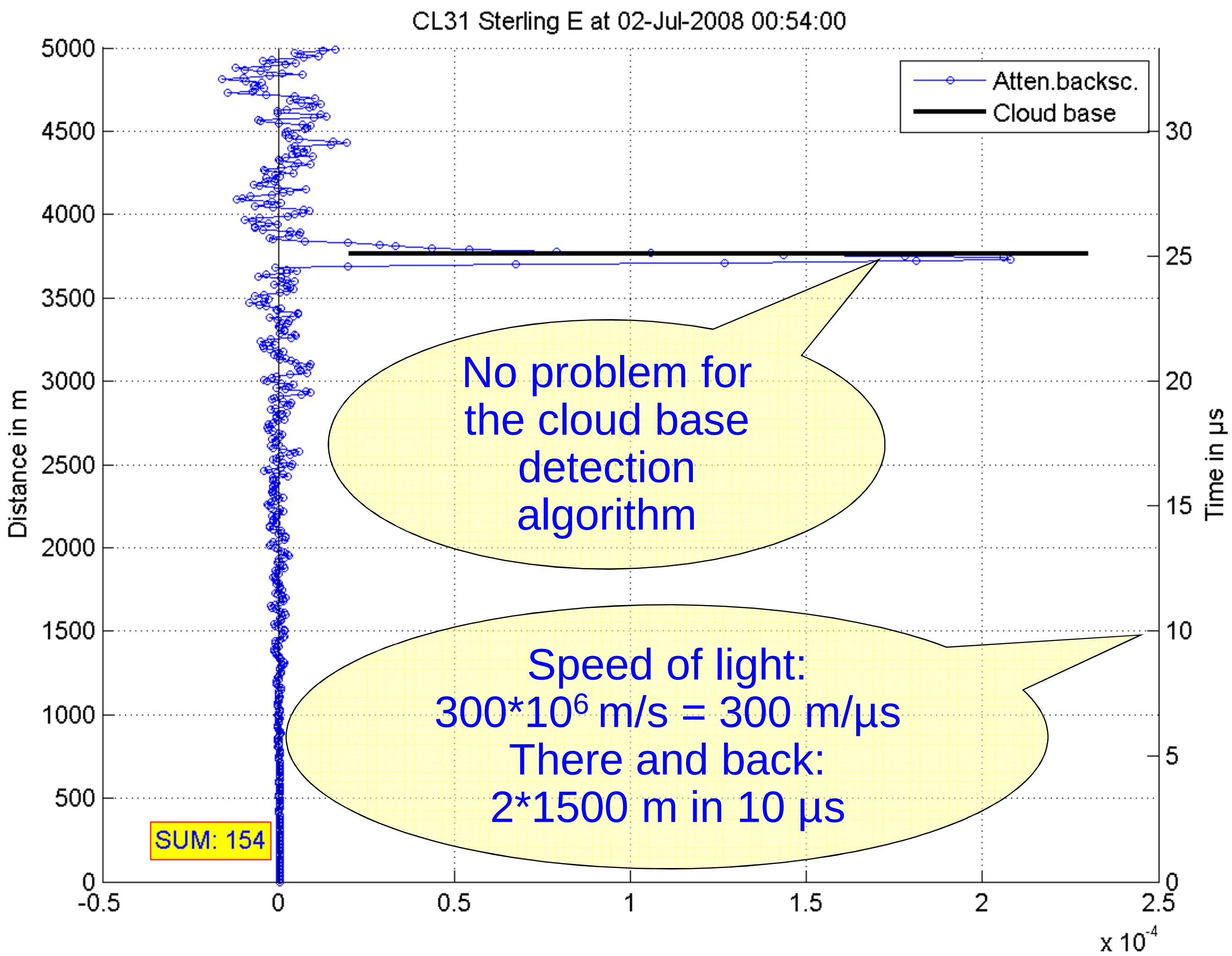
Wien Hohe Warte, Austria
operated by ZAMG



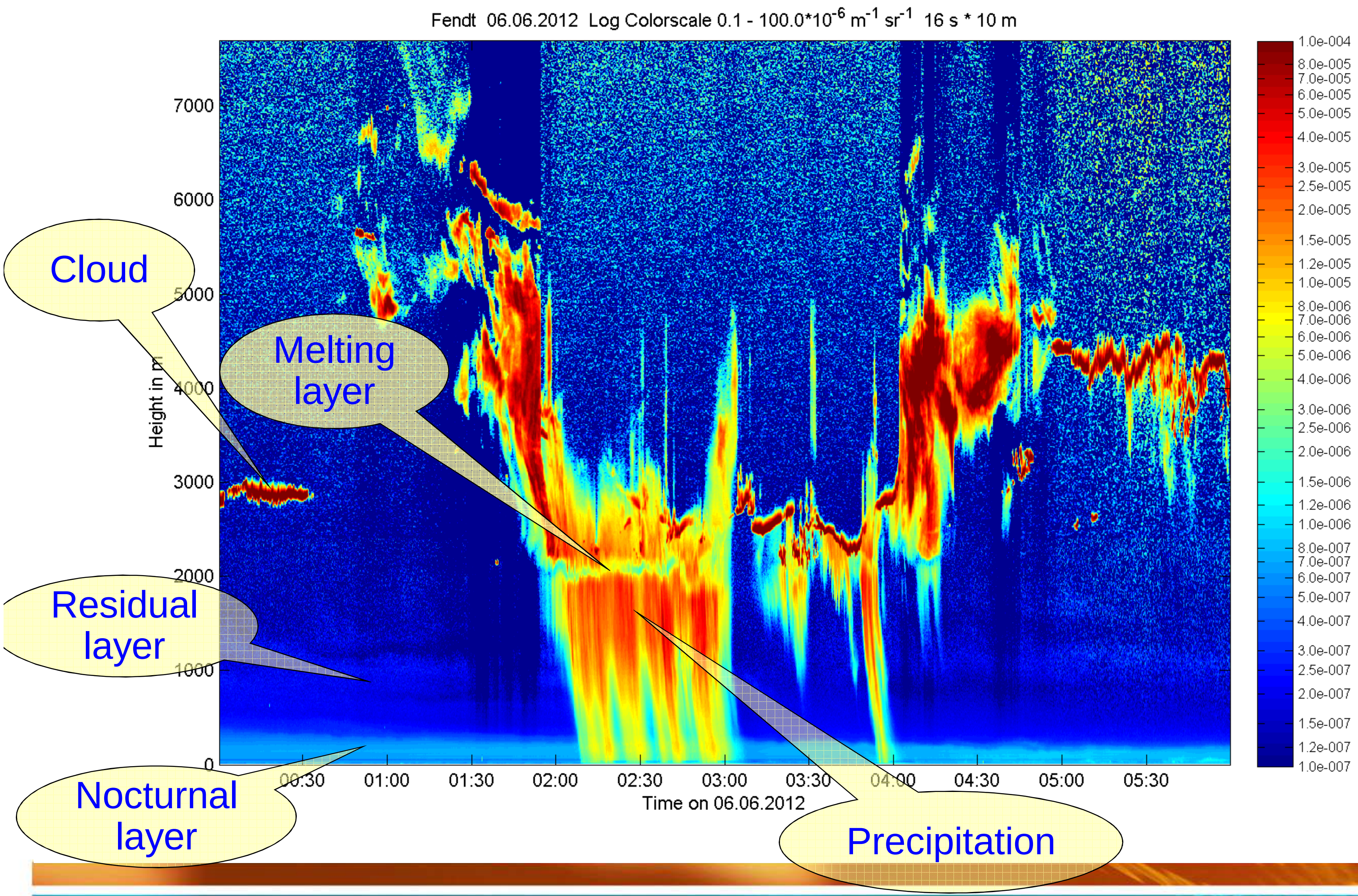
Station Nord, Greenland
operated by DTU Wind Energy, Roskilde

- Unchanged optical setup compared to CL31.
- Larger lens and modified electronics increase SNR significantly.
- Qualified instrument for boundary layer investigation.
- Designed for harsh environments.

16384 laser pulses are accumulated within 2 s for a single reported profile



A typical CL51 backscatter profile density plot

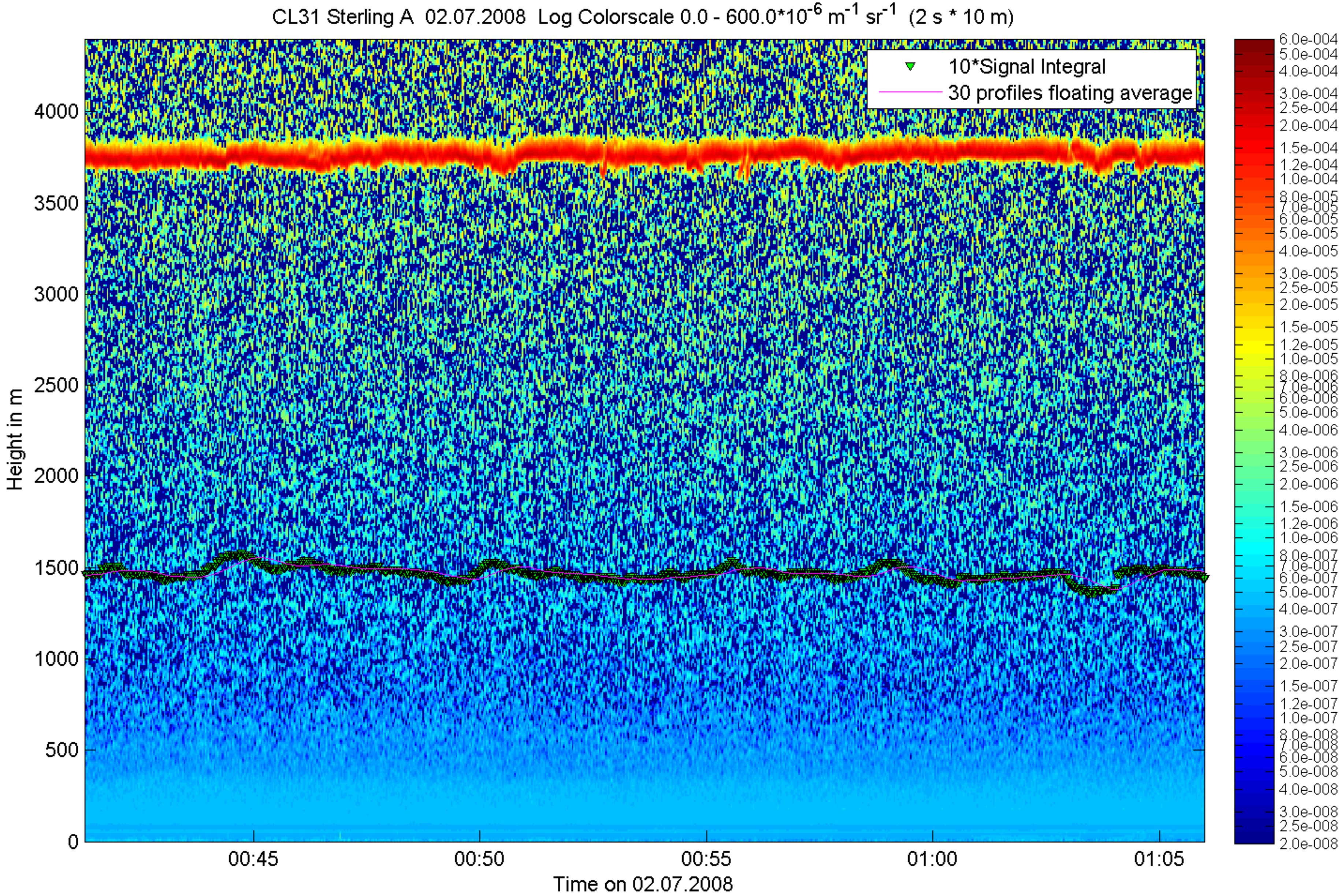


Hot topic in the scientific community – calibration of ceilometers

- WG 1 of TOPROF is investigating the following methods:
  - Rayleigh Calibration
  - Cloud calibration
  - Reference Lidar (not operational)
- Vaisala ceilometers are factory calibrated.
- During operation the calibration factor is maintained by monitoring laser power and window transmission.

Are results from different ceilometers comparable? A random investigation of four co-located CL31 ceilometers

- Before purchasing 1000 CL31 ceilometers, the US National Weather Service did extensive testing.
- For more than two years, up to five co-located ceilometers were operated in a circle with a diameter of 30 m.
- The following slides show 25 minutes with a rather stable 3700 m cloud base.
- Signal integral over the whole measuring range should not differ significantly.
- On the randomnly chosen time 2008-07-02 00:54:00, the average signal integral of the four units was 0.0152 sr^{-1} with a standard deviation of 0.00059 sr^{-1} corresponding to 3.9 %.


CL31 Sterling A 02.07.2008 Log Colorscale 0.0 - 600.0*10^-6 m^-1 sr^-1 (2 s * 10 m)
10*Signal Integral
30 profiles floating average
Height in m
0
500
1000
1500
2000
2500
3000
3500
4000
00:45
00:50
00:55
01:00
01:05
Time on 02.07.2008
6.0e-004
5.0e-004
4.0e-004
3.0e-004
2.5e-004
2.0e-004
1.5e-004
1.2e-004
1.0e-004
8.0e-005
7.0e-005
6.0e-005
5.0e-005
4.0e-005
3.0e-005
2.5e-005
2.0e-005
1.5e-005
1.2e-005
1.0e-005
8.0e-006
7.0e-006
6.0e-006
5.0e-006
4.0e-006
3.0e-006
2.5e-006
2.0e-006
1.5e-006
1.2e-006
1.0e-006
8.0e-007
7.0e-007
6.0e-007
5.0e-007
4.0e-007
3.0e-007
2.5e-007
2.0e-007
1.5e-007
1.2e-007
1.0e-007
8.0e-008
7.0e-008
6.0e-008
5.0e-008
4.0e-008
3.0e-008
2.5e-008
2.0e-008

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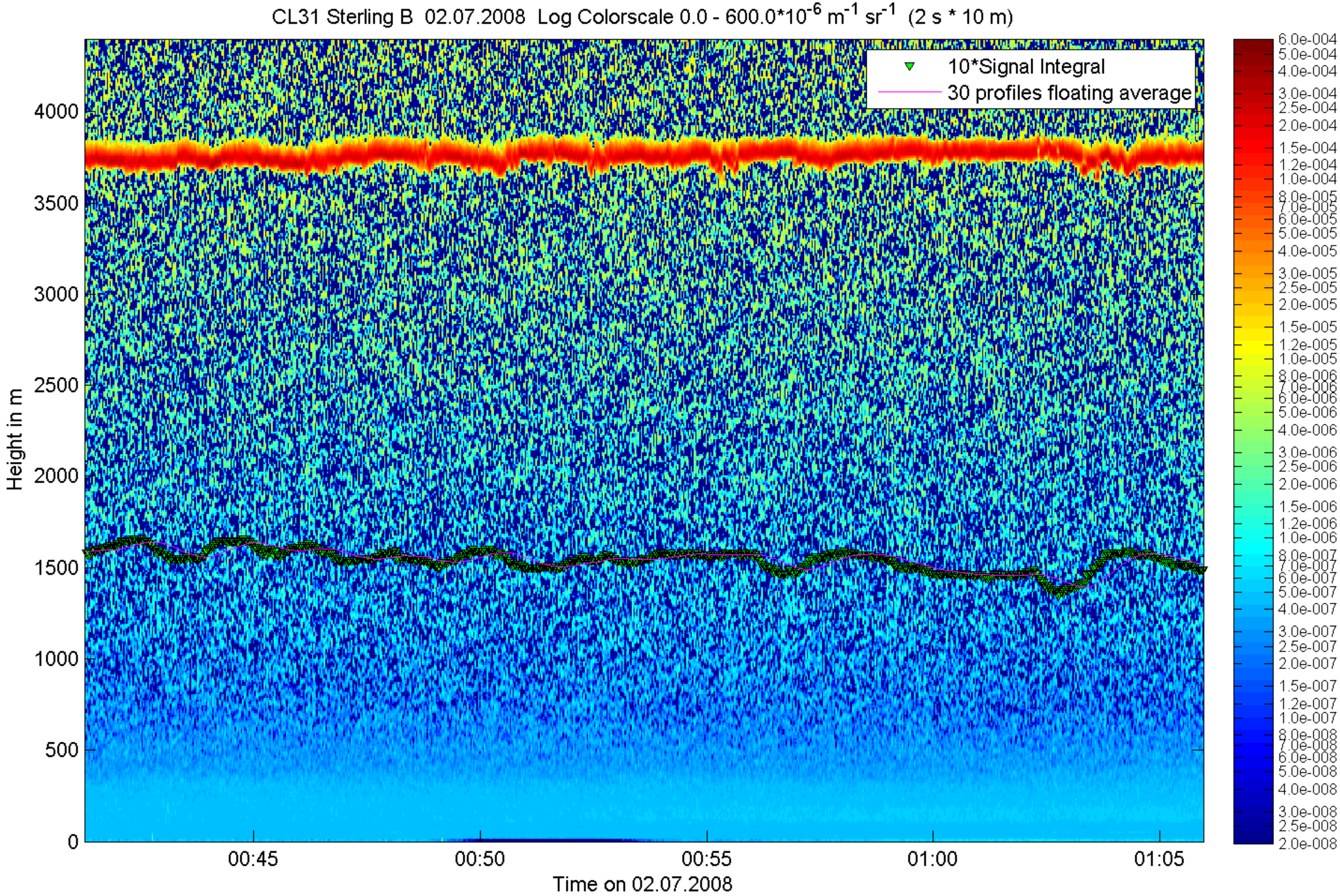
CL31 Sterling B 02.07.2008 Log Colorscale 0.0 - 600.0*10^-6 m^-1 sr^-1 (2 s * 10 m)
10*Signal Integral
30 profiles floating average
Height in m
4000
3500
3000
2500
2000
1500
1000
500
0
00:45
00:50
00:55
01:00
01:05
Time on 02.07.2008
6.0e-004
5.0e-004
4.0e-004
3.0e-004
2.5e-004
2.0e-004
1.5e-004
1.2e-004
1.0e-004
8.0e-005
7.0e-005
6.0e-005
5.0e-005
4.0e-005
3.0e-005
2.5e-005
2.0e-005
1.5e-005
1.2e-005
1.0e-005
8.0e-006
7.0e-006
6.0e-006
5.0e-006
4.0e-006
3.0e-006
2.5e-006
2.0e-006
1.5e-006
1.2e-006
1.0e-006
8.0e-007
7.0e-007
6.0e-007
5.0e-007
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2.0e-007
1.5e-007
1.2e-007
1.0e-007
8.0e-008
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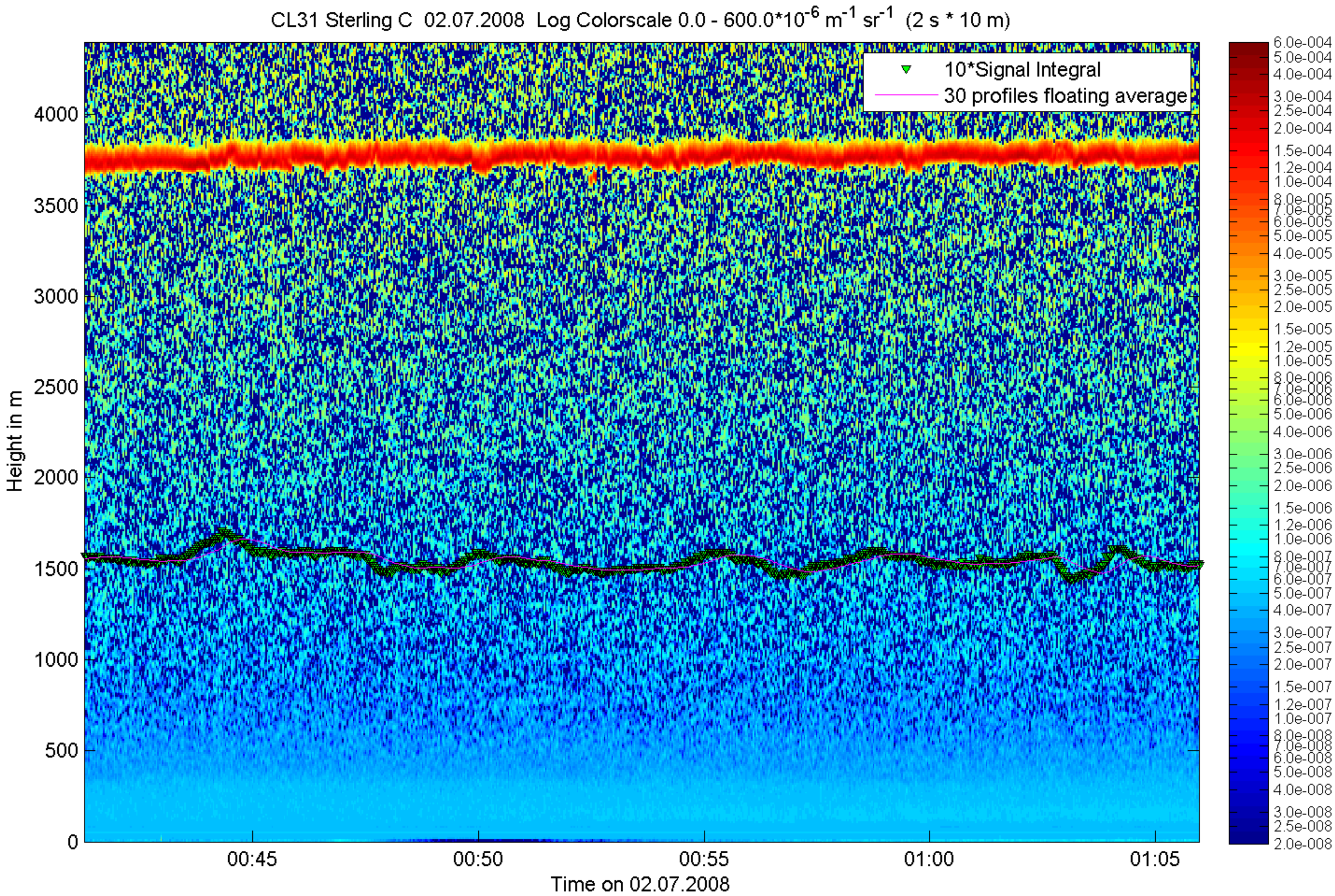
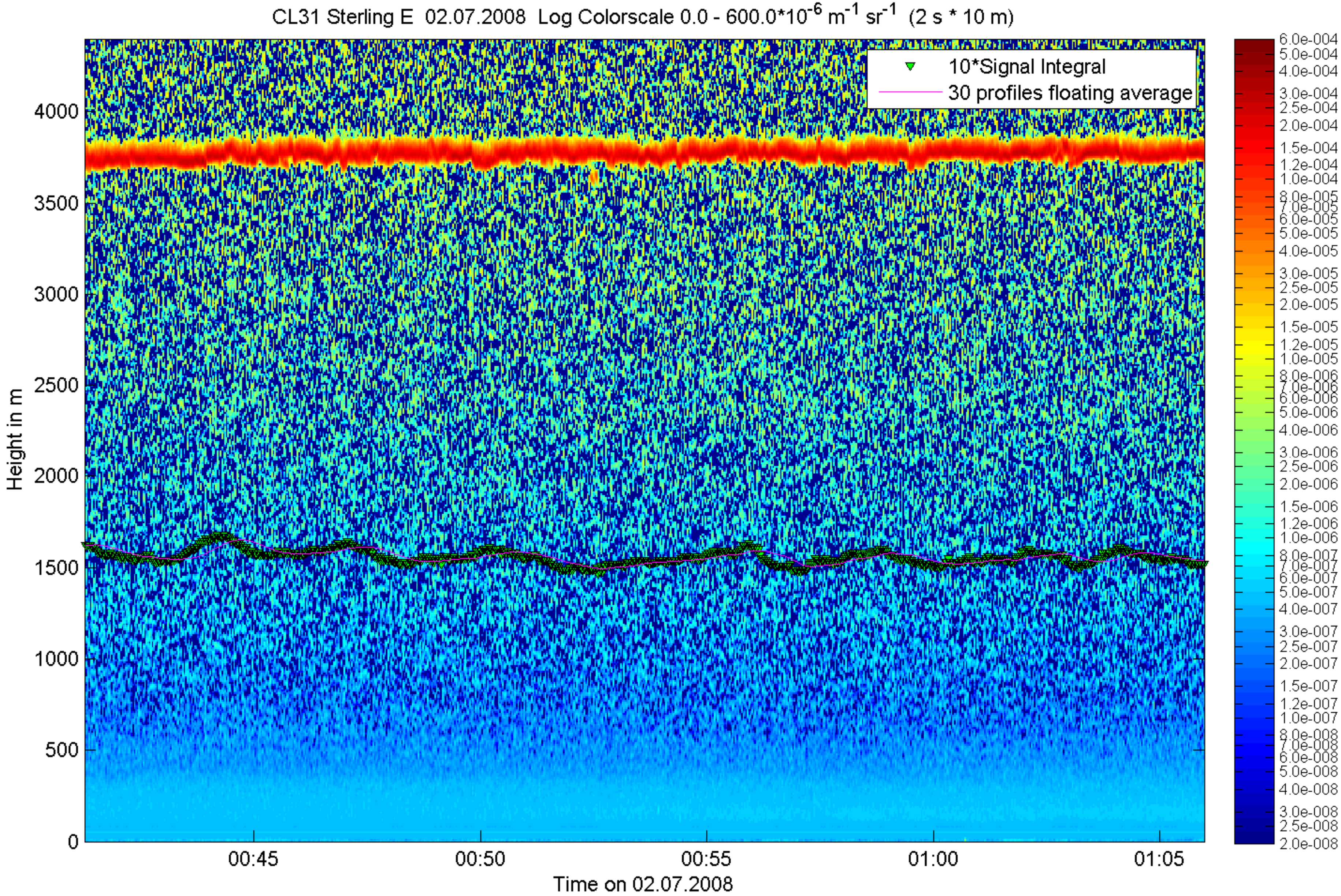
4.0e-008
3.0e-008
2.5e-008
2.0e-008



CL31 Sterling C 02.07.2008 Log Colorscale 0.0 - 600.0*10^-6 m^-1 sr^-1 (2 s * 10 m)
10*Signal Integral
30 profiles floating average
Height in m
4000
3500
3000
2500
2000
1500
1000
500
0
00:45
00:50
00:55
01:00
01:05
Time on 02.07.2008
6.0e-004
5.0e-004
4.0e-004
3.0e-004
2.5e-004
2.0e-004
1.5e-004
1.2e-004
1.0e-004
8.0e-005
7.0e-005
6.0e-005
5.0e-005
4.0e-005
3.0e-005
2.5e-005
2.0e-005
1.5e-005
1.2e-005
1.0e-005
8.0e-006
7.0e-006
6.0e-006
5.0e-006
4.0e-006
3.0e-006
2.5e-006
2.0e-006
1.5e-006
1.2e-006
1.0e-006
8.0e-007
7.0e-007
6.0e-007
5.0e-007
4.0e-007
3.0e-007
2.5e-007
2.0e-007
1.5e-007
1.2e-007
1.0e-007
8.0e-008
7.0e-008
6.0e-008
5.0e-008
4.0e-008
3.0e-008
2.5e-008
2.0e-008


CL31 Sterling E 02.07.2008 Log Colorscale 0.0 - 600.0*10^-6 m^-1 sr^-1 (2 s * 10 m)
10*Signal Integral
30 profiles floating average
Height in m
4000
3500
3000
2500
2000
1500
1000
500
0
00:45
00:50
00:55
01:00
01:05
Time on 02.07.2008
6.0e-004
5.0e-004
4.0e-004
3.0e-004
2.5e-004
2.0e-004
1.5e-004
1.2e-004
1.0e-004
8.0e-005
7.0e-005
6.0e-005
5.0e-005
4.0e-005
3.0e-005
2.5e-005
2.0e-005
1.5e-005
1.2e-005
1.0e-005
8.0e-006
7.0e-006
6.0e-006
5.0e-006
4.0e-006
3.0e-006
2.5e-006
2.0e-006
1.5e-006
1.2e-006
1.0e-006
8.0e-007
7.0e-007
6.0e-007
5.0e-007
4.0e-007
3.0e-007
2.5e-007
2.0e-007
1.5e-007
1.2e-007
1.0e-007
8.0e-008
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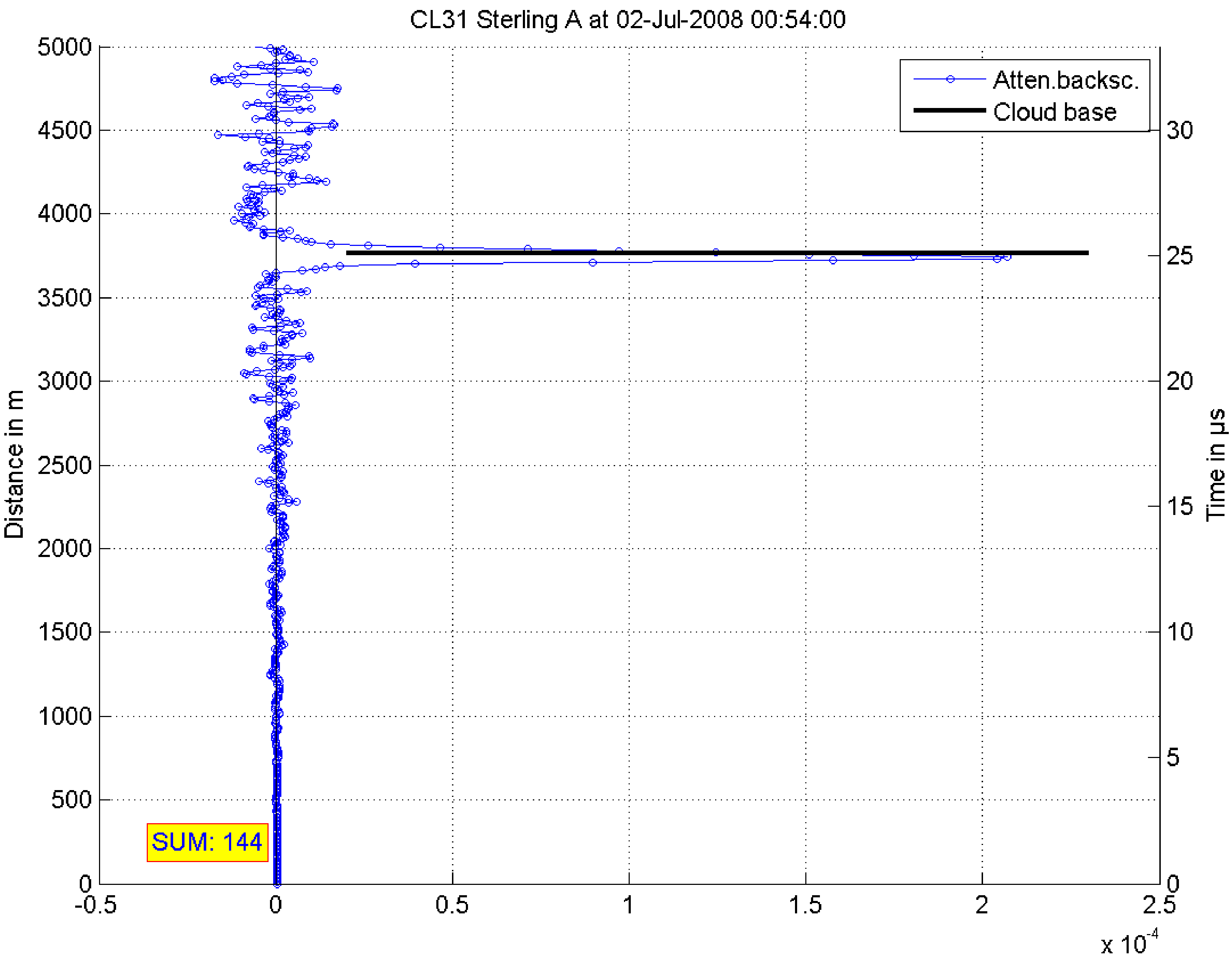
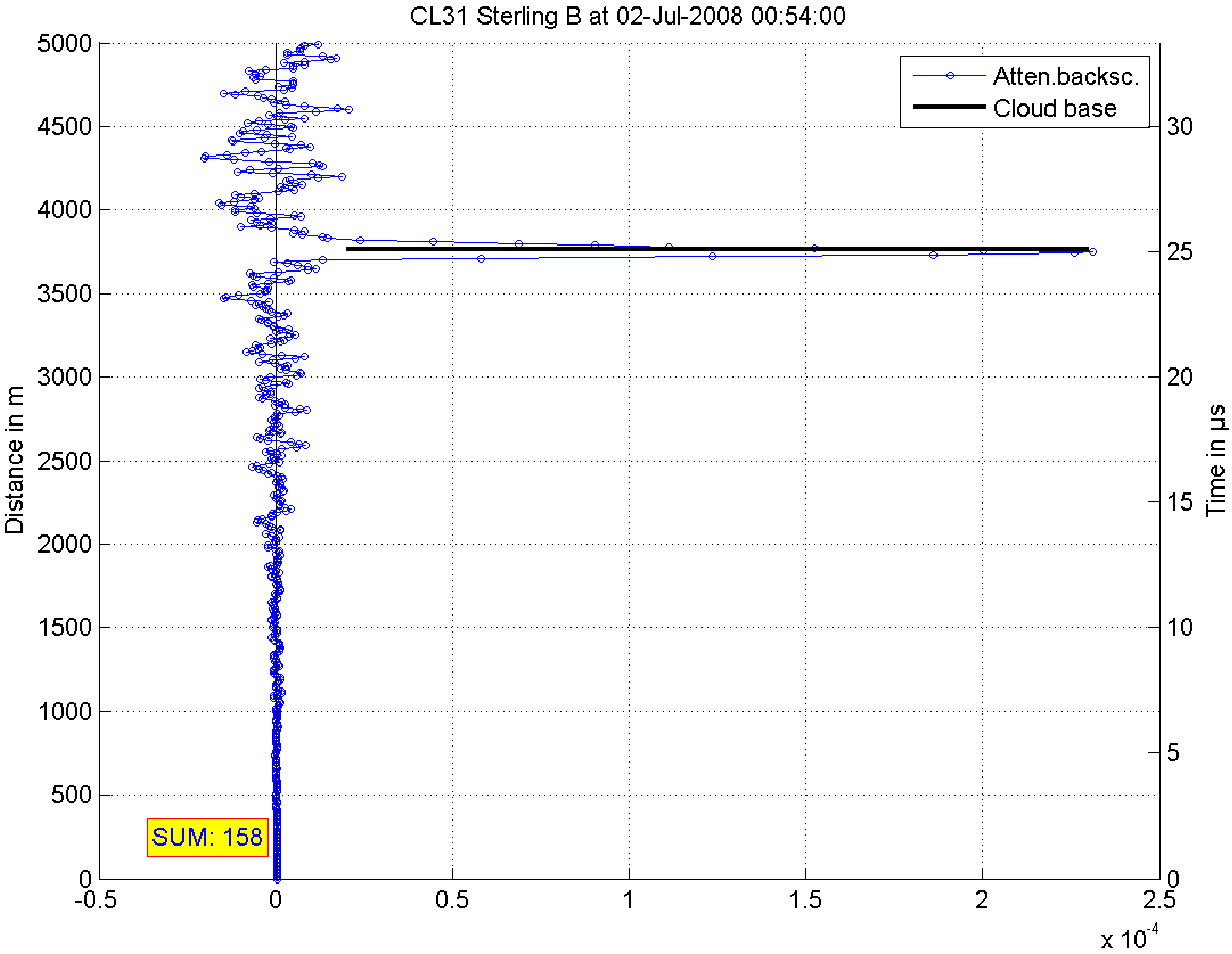
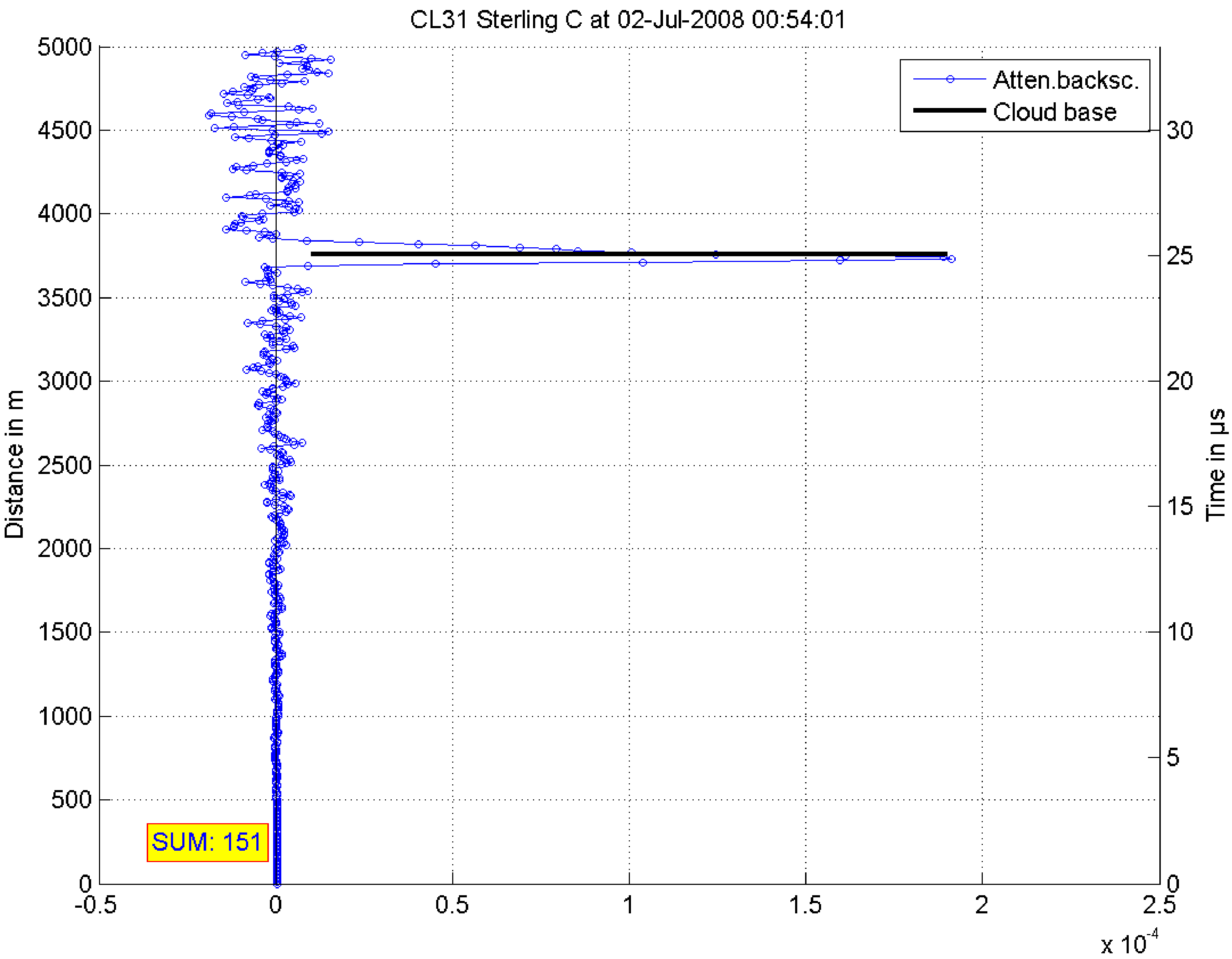
3.0e-008
2.5e-008
2.0e-008

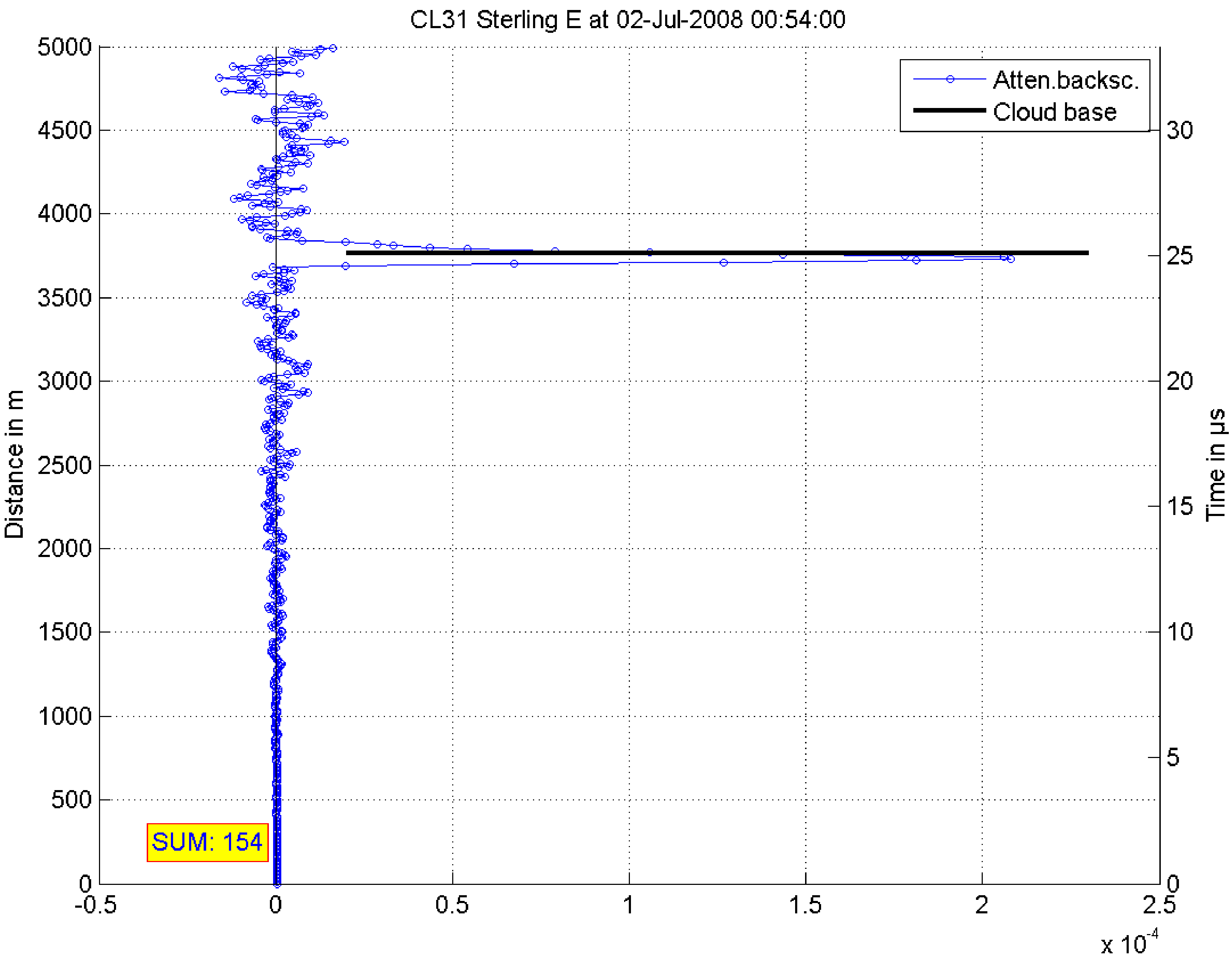


CL31 Sterling A at 02-Jul-2008 00:54:00
Atten.backsc.
Cloud base
SUM: 144
Distance in m
Time in µs
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
30
25
20
15
10
5
0
-0.5
0
0.5
1
1.5
2
2.5
x 10^-4


CL31 Sterling B at 02-Jul-2008 00:54:00
Atten.backsc.
Cloud base
Distance in m
Time in µs
SUM: 158
x 10^-4
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
-0.5
0
0.5
1
1.5
2
2.5
30
25
20
15
10
5
0



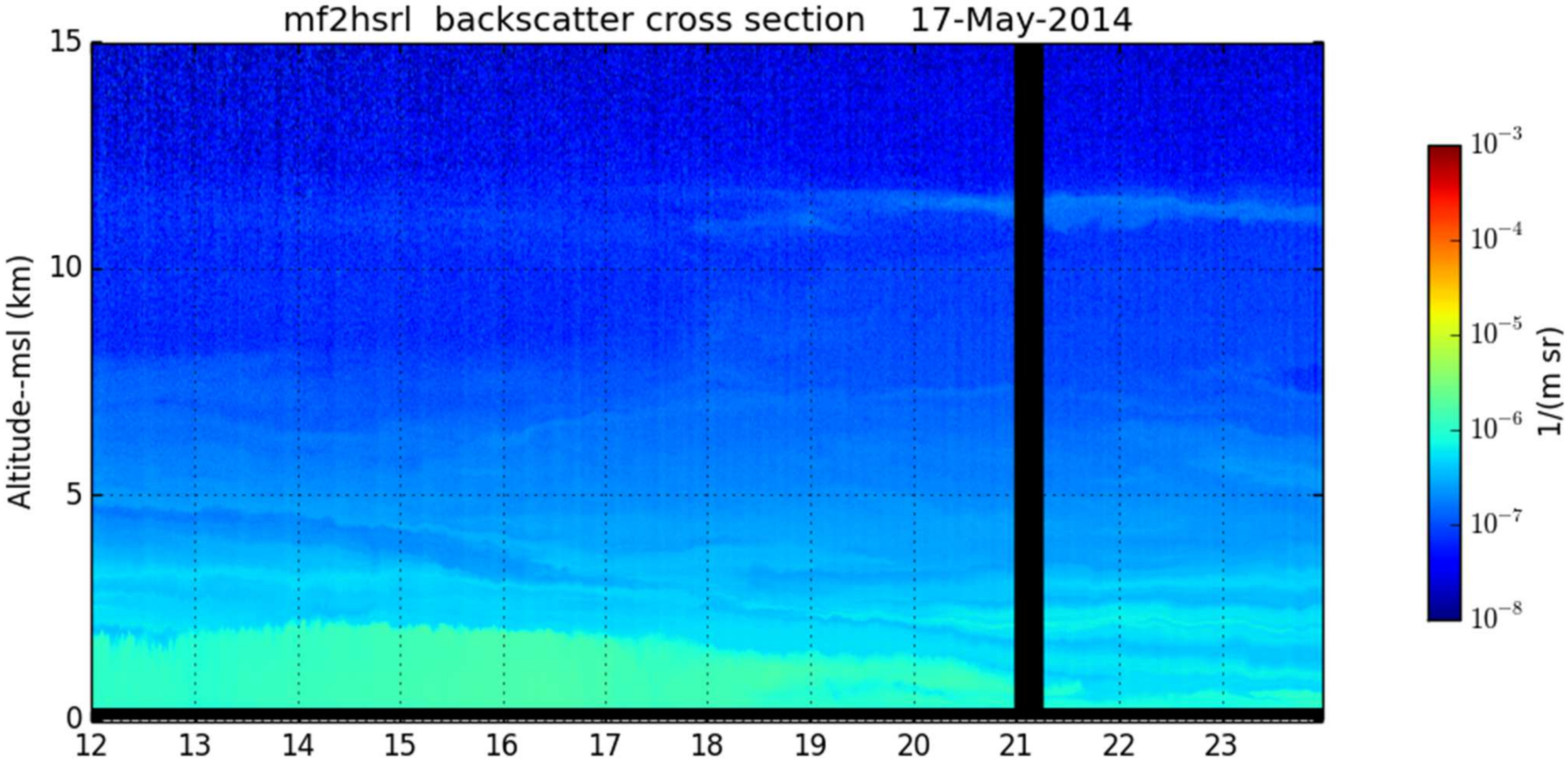
CL31 Sterling C at 02-Jul-2008 00:54:01
Atten.backsc.
Cloud base
Distance in m
Time in µs
SUM: 151
x 10^-4
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
-0.5
0
0.5
1
1.5
2
2.5
5
10
15
20
25
30


CL31 Sterling E at 02-Jul-2008 00:54:00
Atten.backsc.
Cloud base
Distance in m
Time in µs
SUM: 154
x 10^-4
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
30
25
20
15
10
5
0
-0.5
0
0.5
1
1.5
2
2.5

Some thoughts about Rayleigh calibration

- Rayleigh calibration method requires ceilometer data from a very clear night, averaged over several hours.
- It tries to identify regions within the attenuated backscatter profile that are practically aerosol free.
- But how can we be sure that we chose the right region?
- The following examples show that there is very often something up there that a ceilometer has difficulties to see.
- Consequently Vaisala favours the cloud calibration method introduced by Ewan O'Connor. http://www.met.reading.ac.uk/~swr99ejo/publications/lidar_calibration.pdf

HSRL at Hyytiälä – a powerful lidar reveals a lot of elevated aerosol layers



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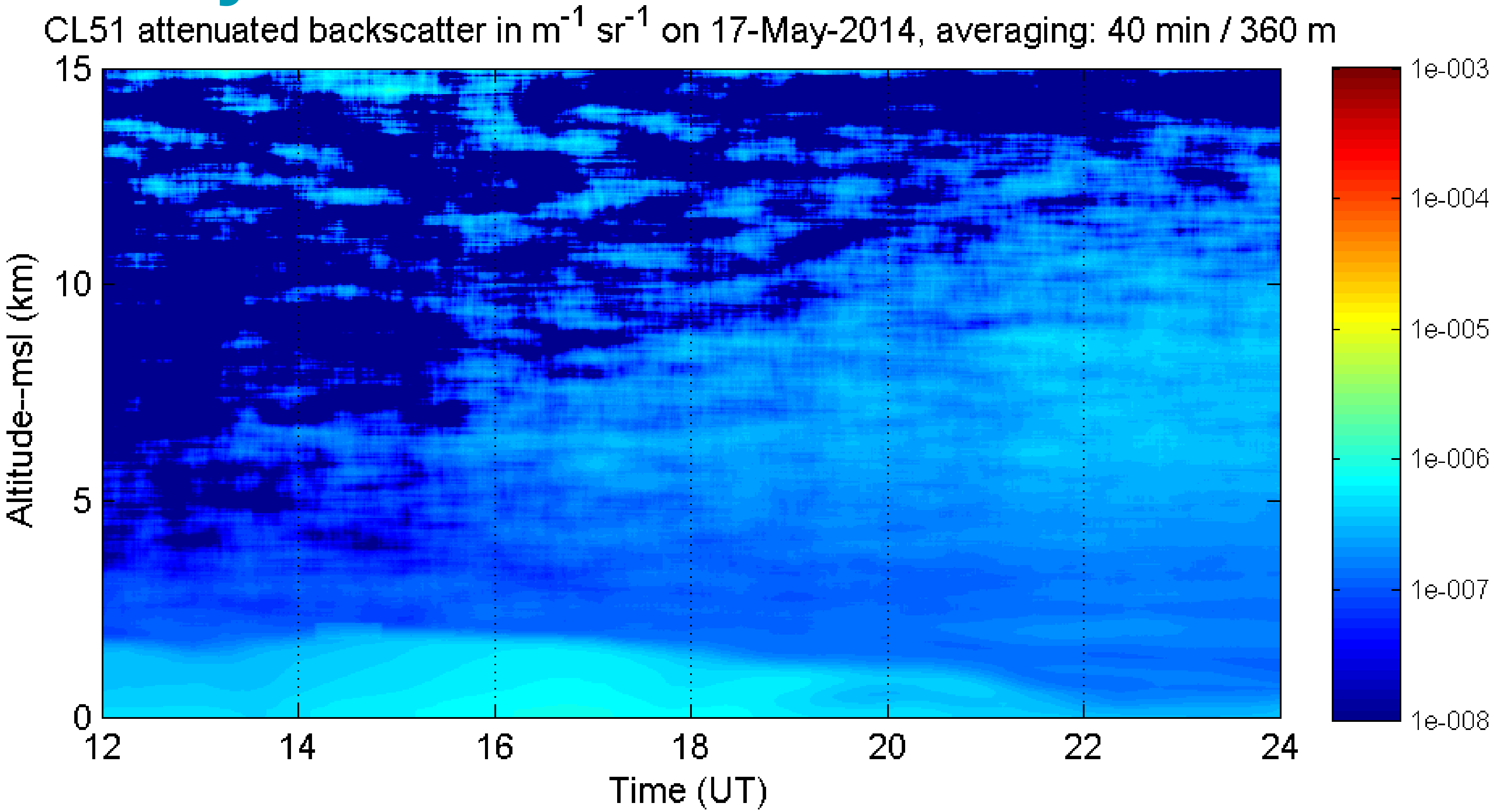
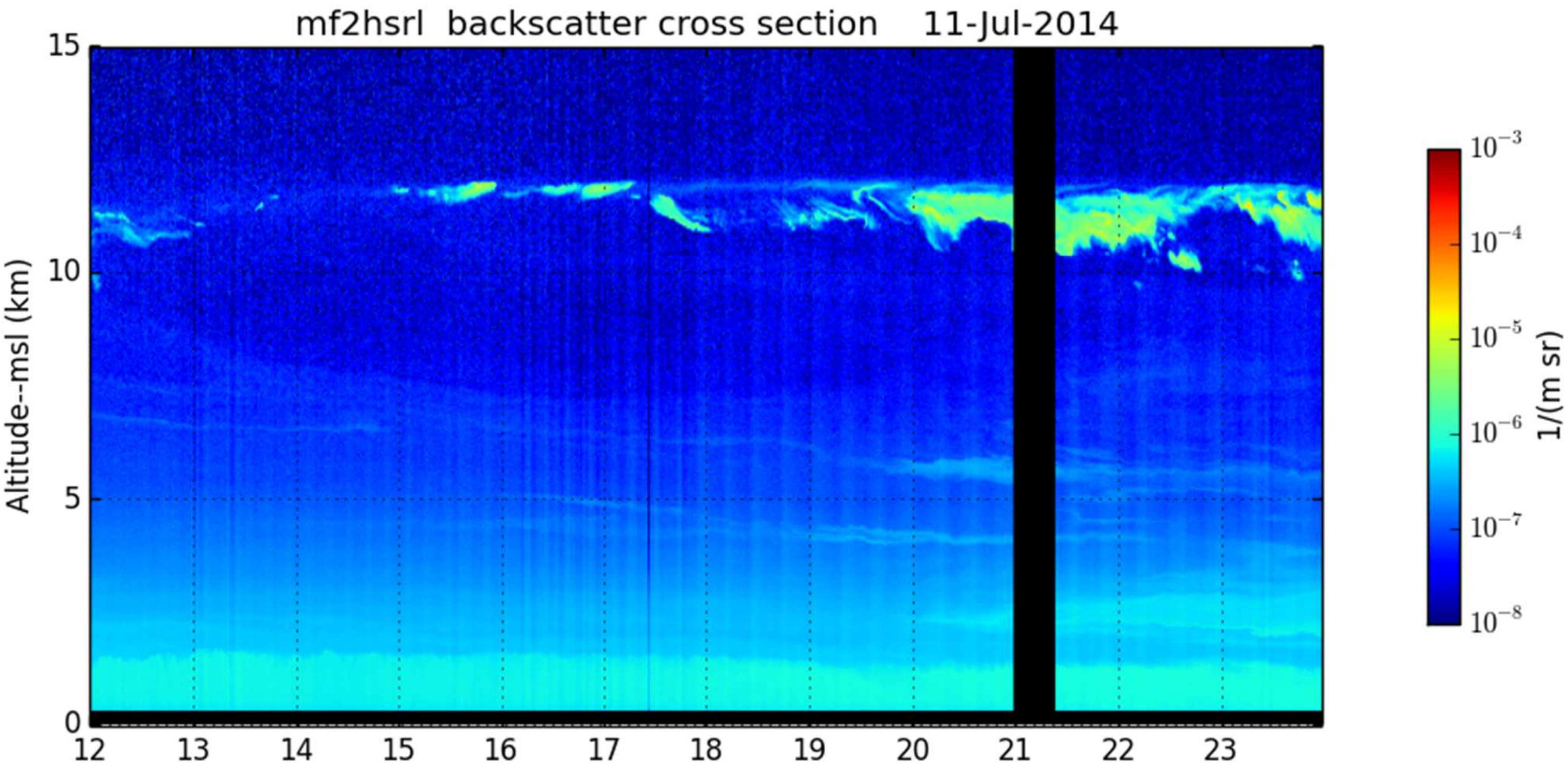
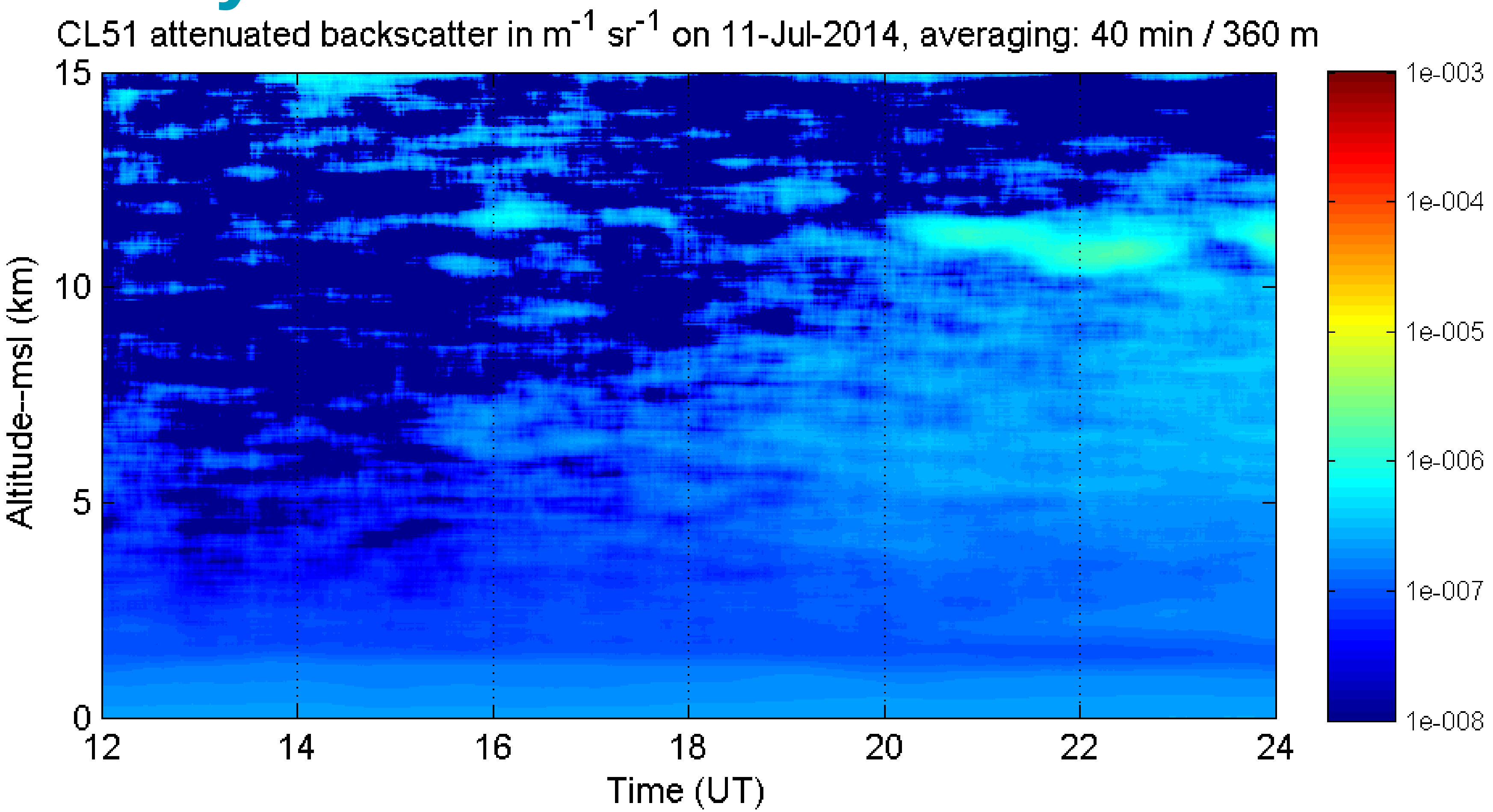
CL51 at Hyytiälä – HSRL structures are barely visible



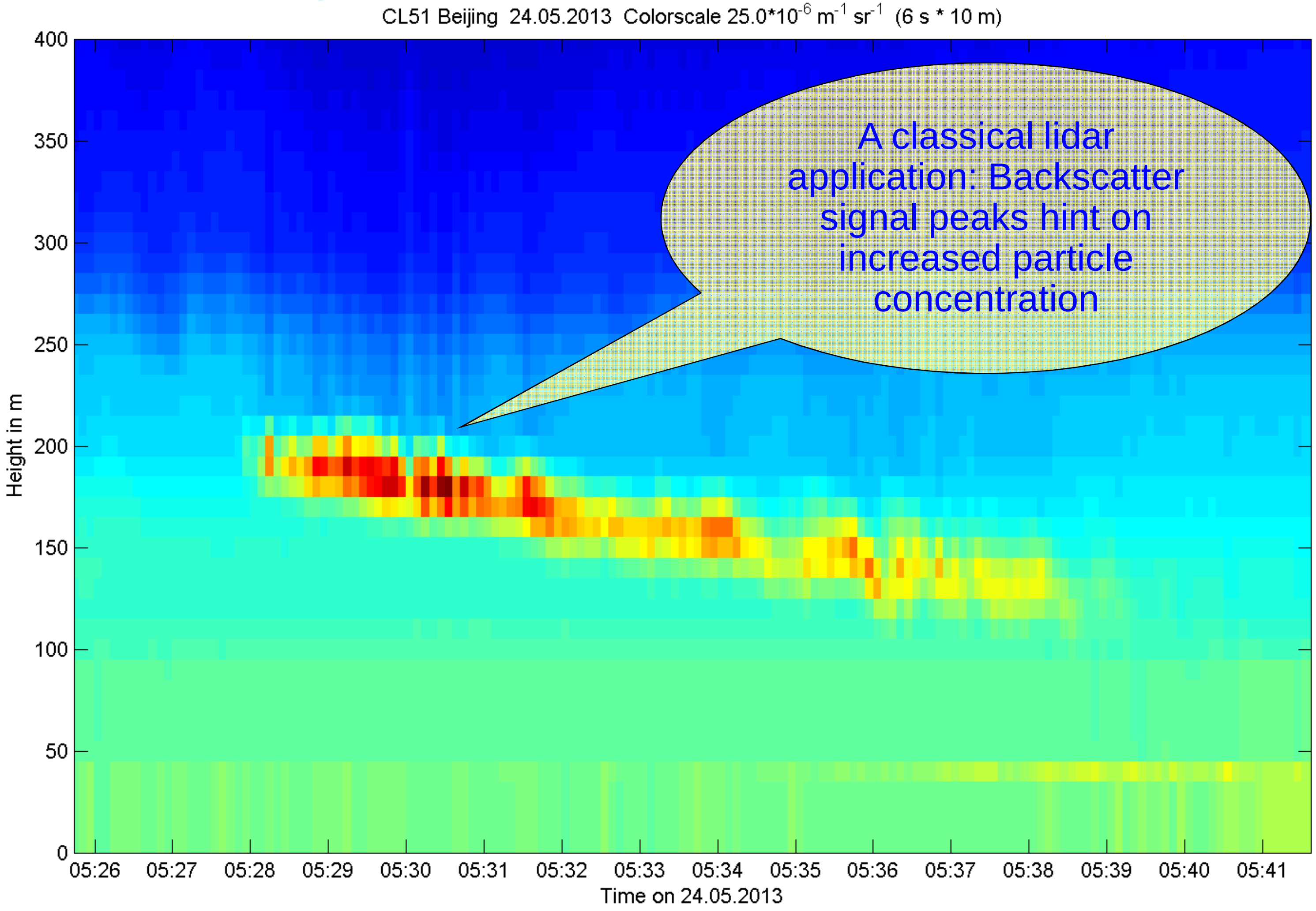
HSRL at Hyytiälä – a powerful lidar reveals a lot of elevated aerosol layers



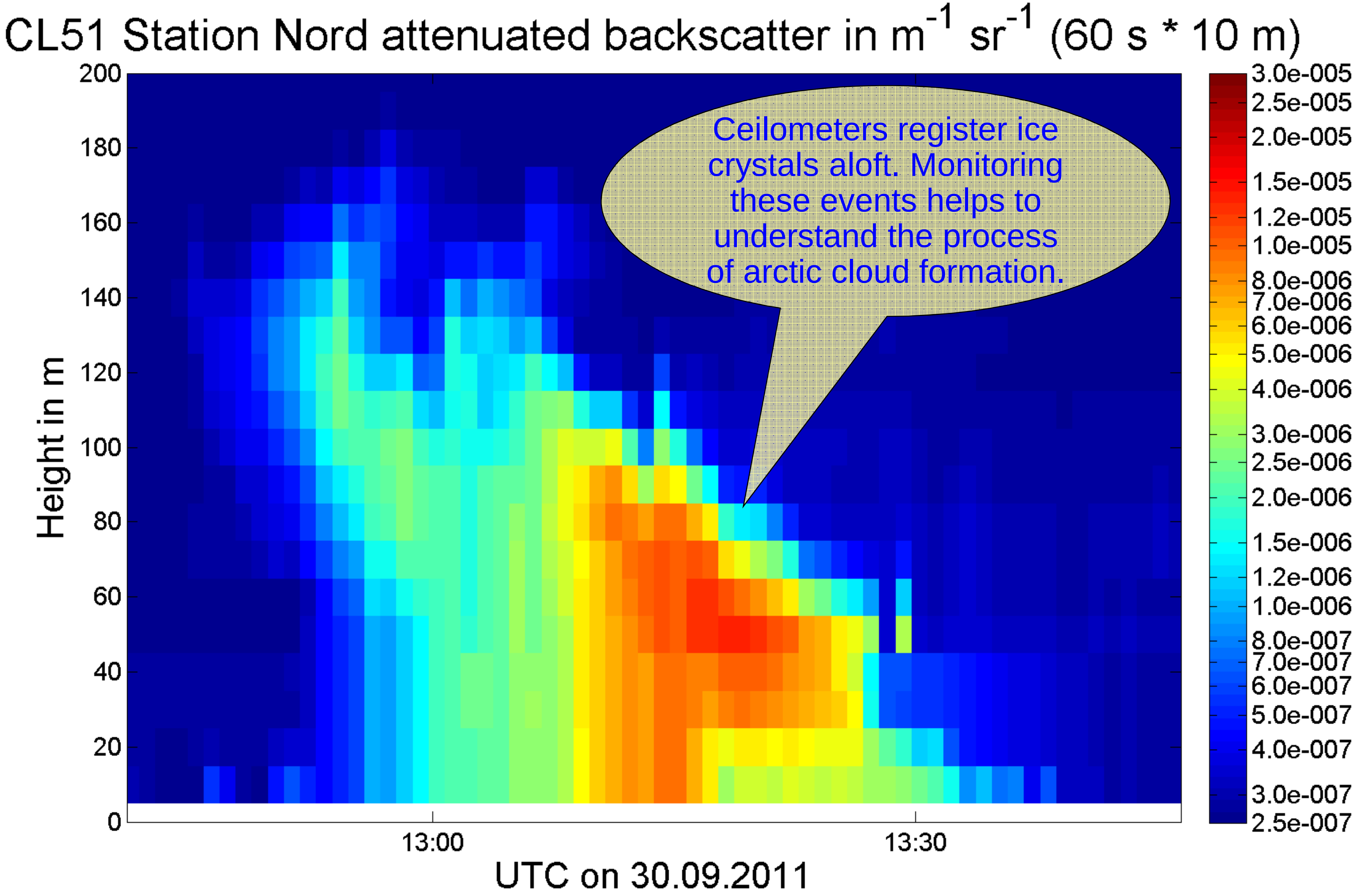
CL51 at Hyytiälä – HSRL structures are barely visible



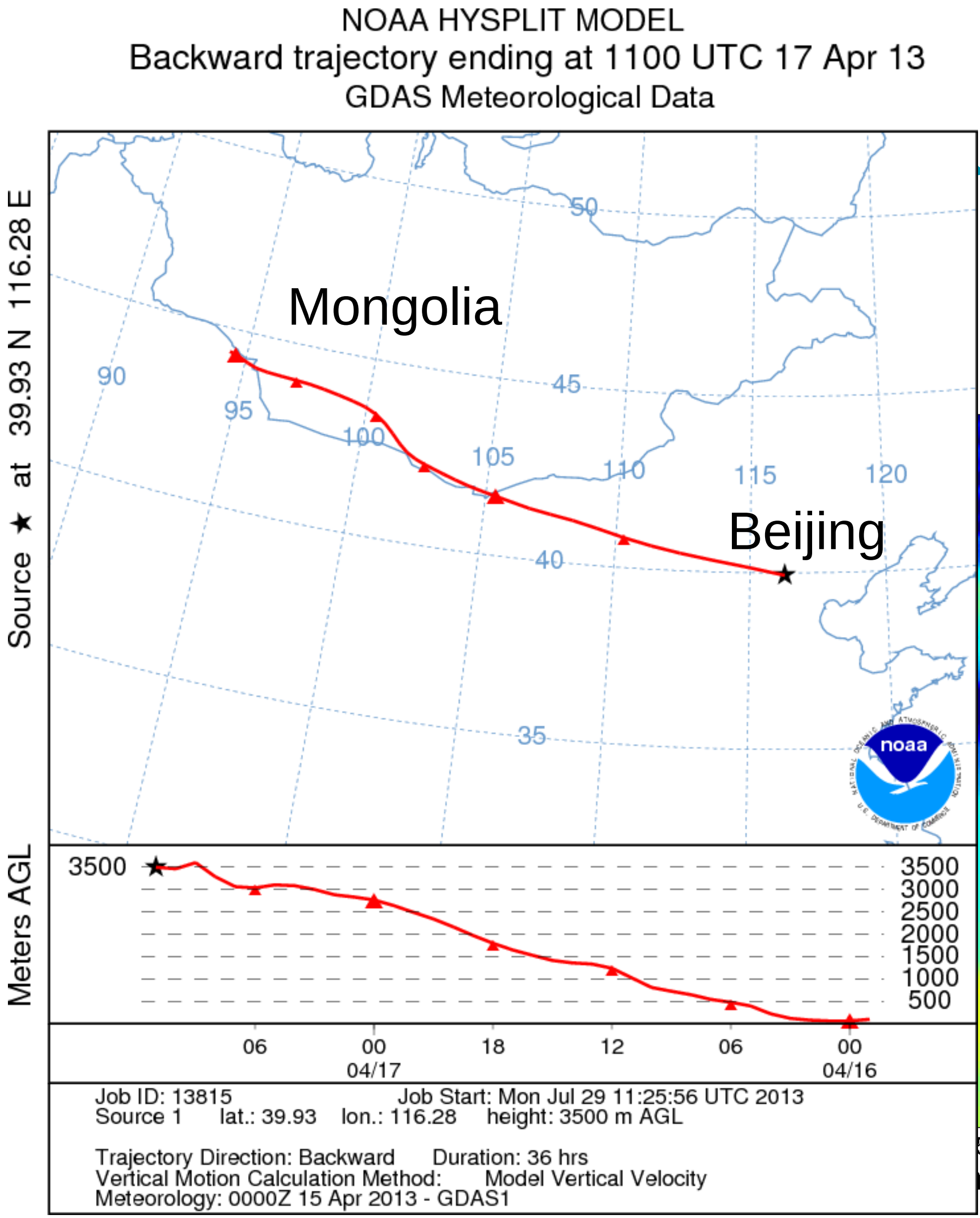
Monitoring particle emissions

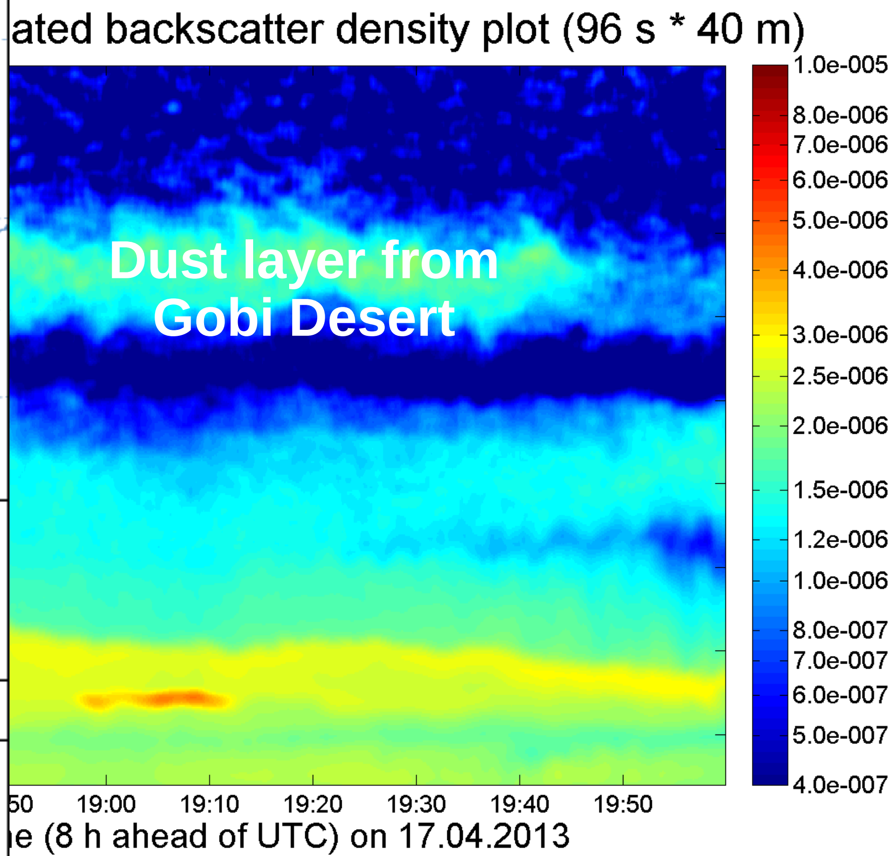


Monitoring particle emissions



sh layers





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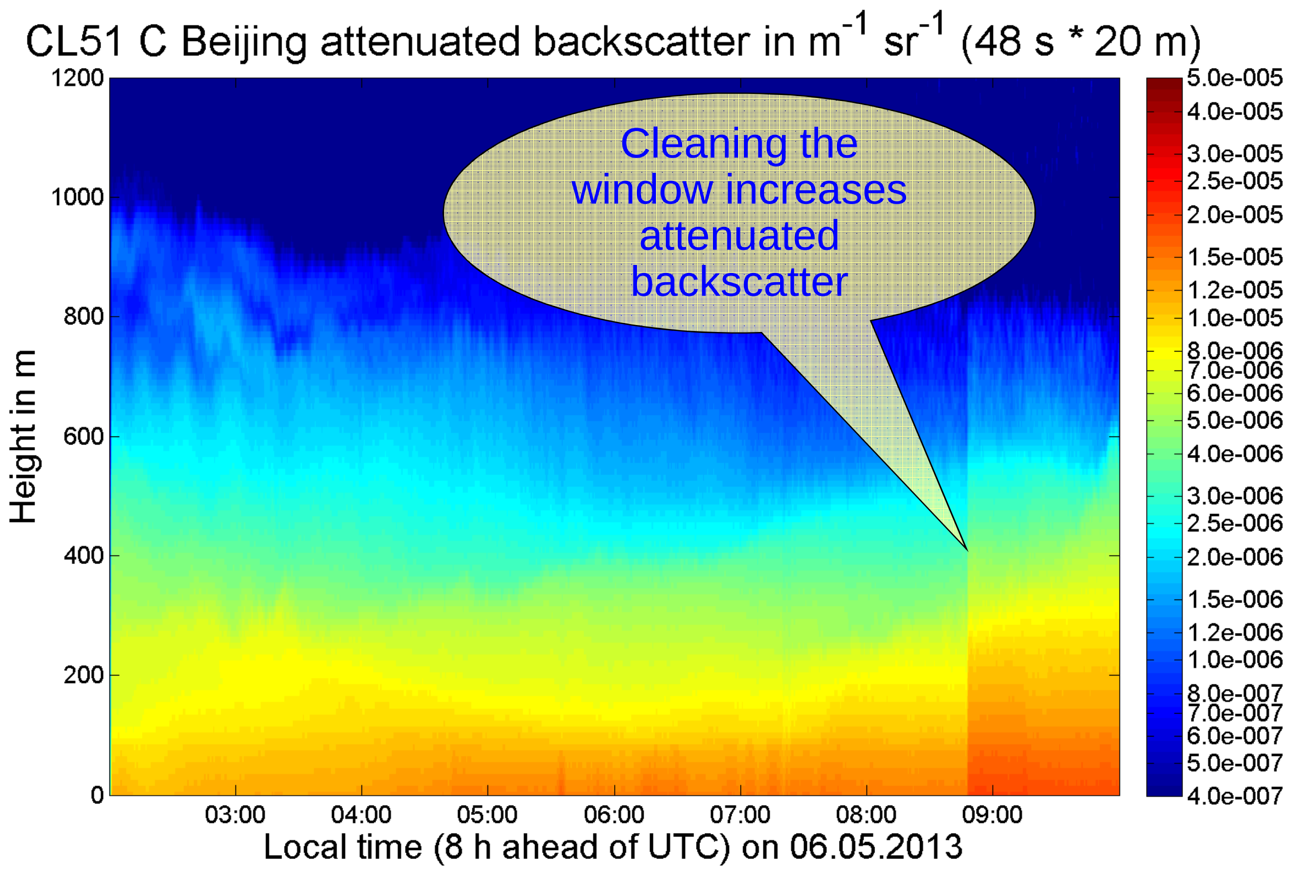
Extinction profiles

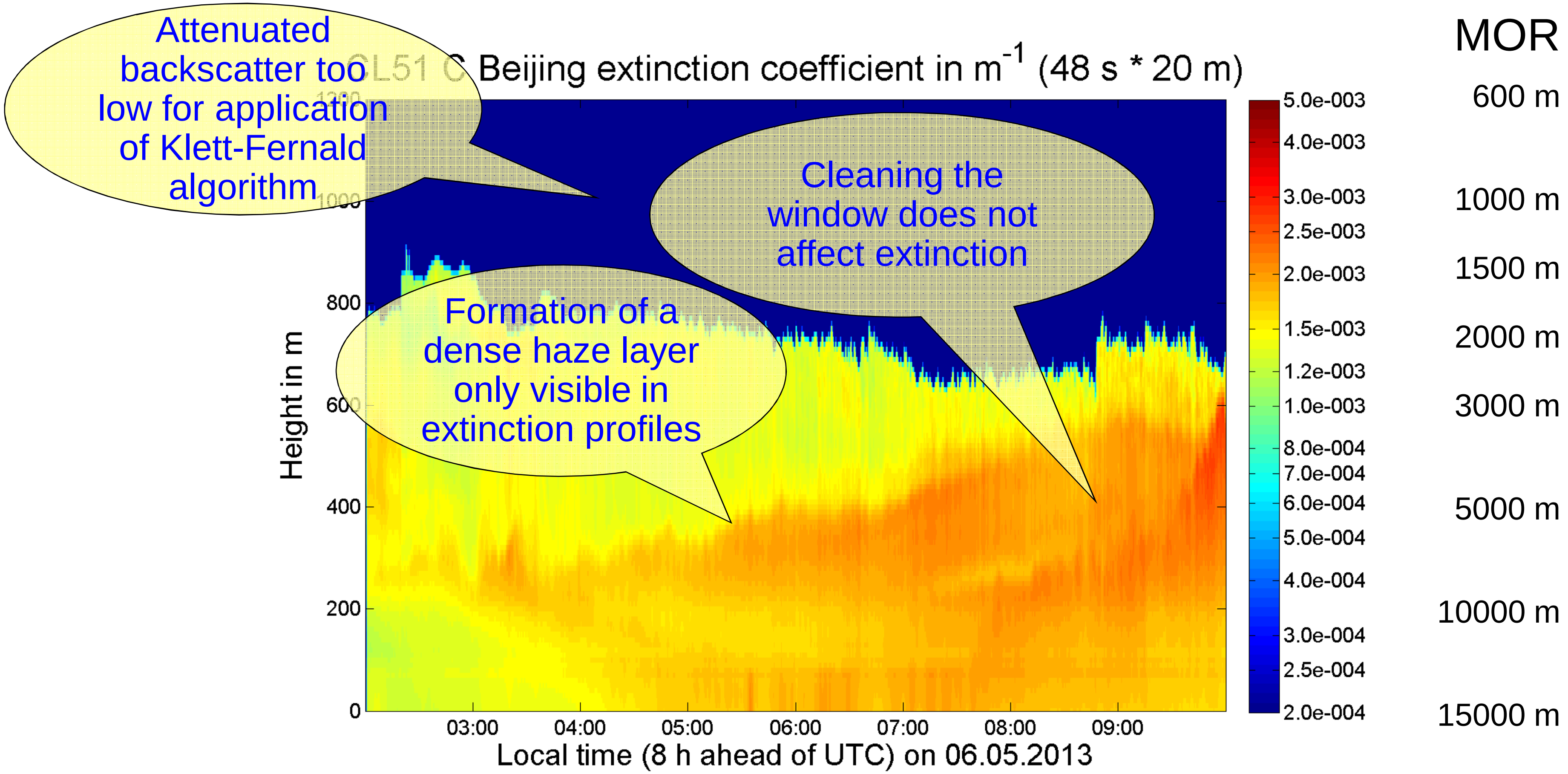
$$P(x,\lambda) = \frac{c}{2x^2} \underbrace{P_0 A \eta O(x) \Delta t}_{\text{instrument specific}} \underbrace{\beta(x,\lambda)\tau^2(x,\lambda)}_{\text{attenuated backscatter}} \qquad \tau(x,\lambda) = \exp\left[-\int_0^x \alpha(\xi,\lambda)\mathrm{d}\xi\right]$$

- Ceilometers report the attenuated backscatter part of the simplified lidar equation.
- According to ISO 28902-1 (ground-based remote sensing of visual range by lidar), profiles of the extinction coefficient α can be derived from this if
  - $\alpha \geq 0.0015\ \mathrm{m}^{-1}$ (corresponding to MOR ≤ 2000 m),
  - a linear and range-independent relation of α and β is assumed.
- These assumptions are fulfilled to a high extent during haze events in megacities.

A haze event in Beijing – attenuated backscatter



A haze event in Beijing – extinction profiles increase information content



Ground extinction coefficient verification with MOR

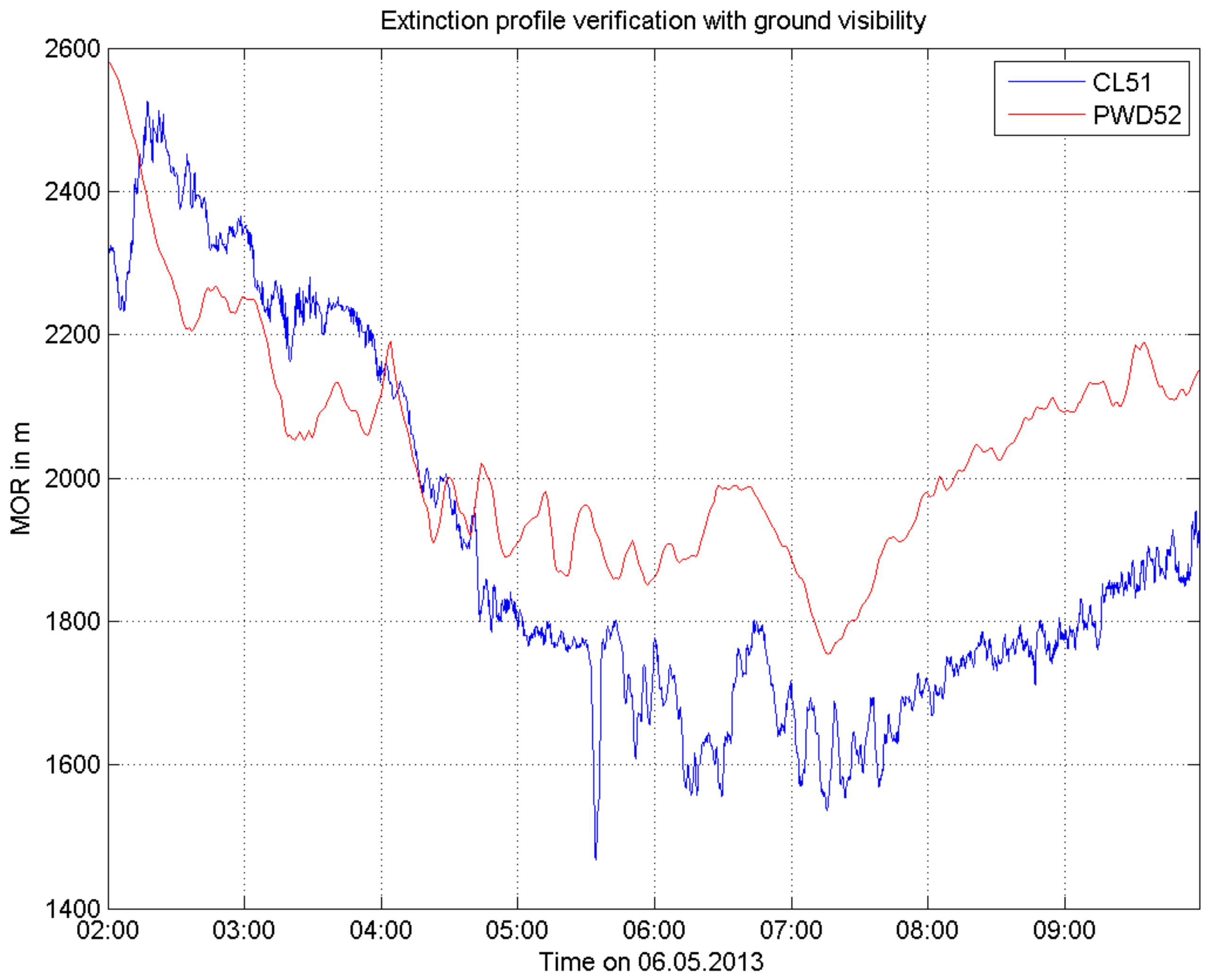
- There are various CL51 installations with attached visibility meter reporting MOR (meteorological optical range).
- These values could be used to verify the validity of the assumptions made for the derivation of extinction profiles.

CL51 and Vaisala FS11 on research vessel Polarstern

CL51 and Vaisala PWD52 at Wien Hohe Warte

CL51 and Vaisala PWD52 on FINO3 platform

Extinction coefficient verification with forward scatter visibility meter PWD52



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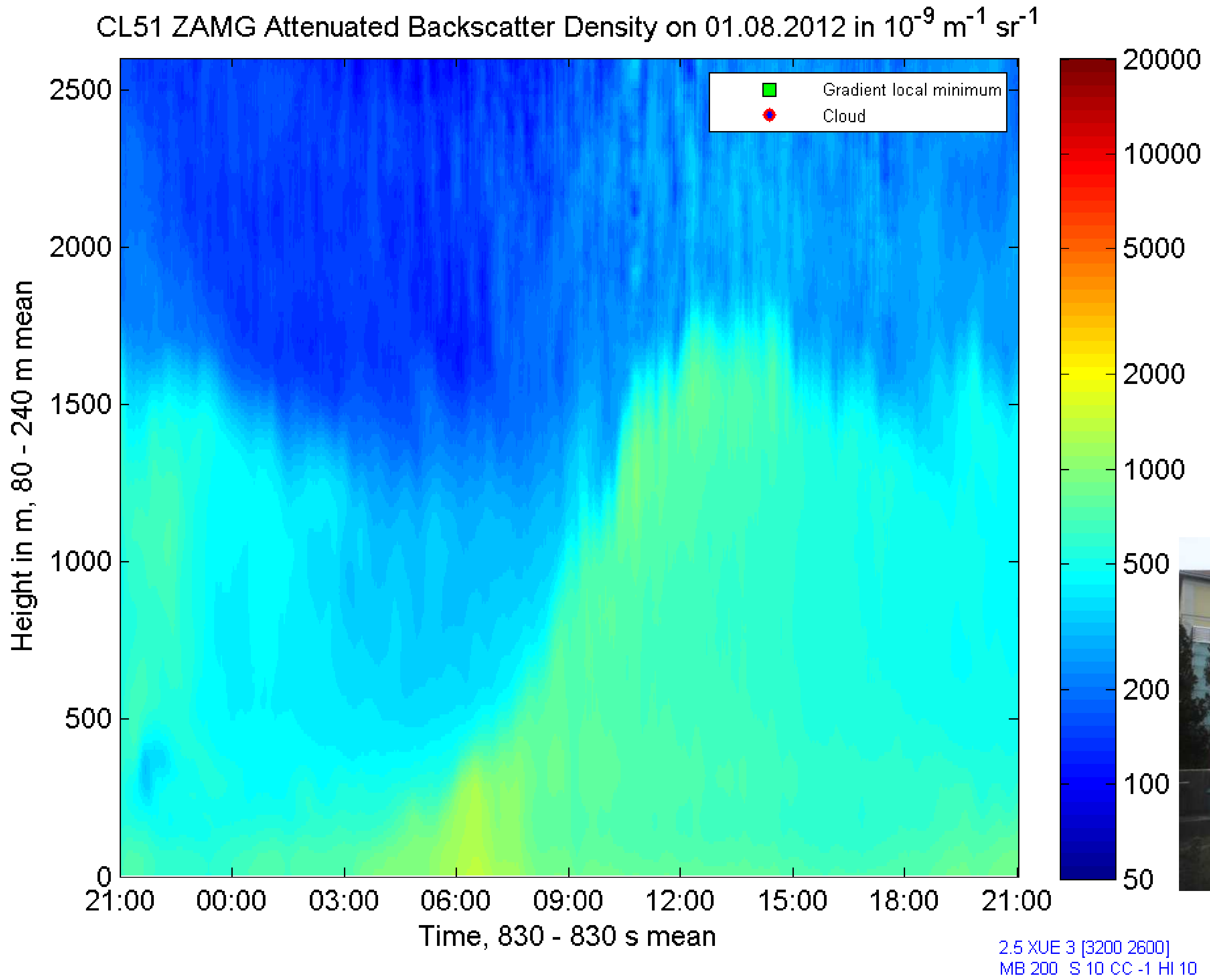
Mixing layer height determination



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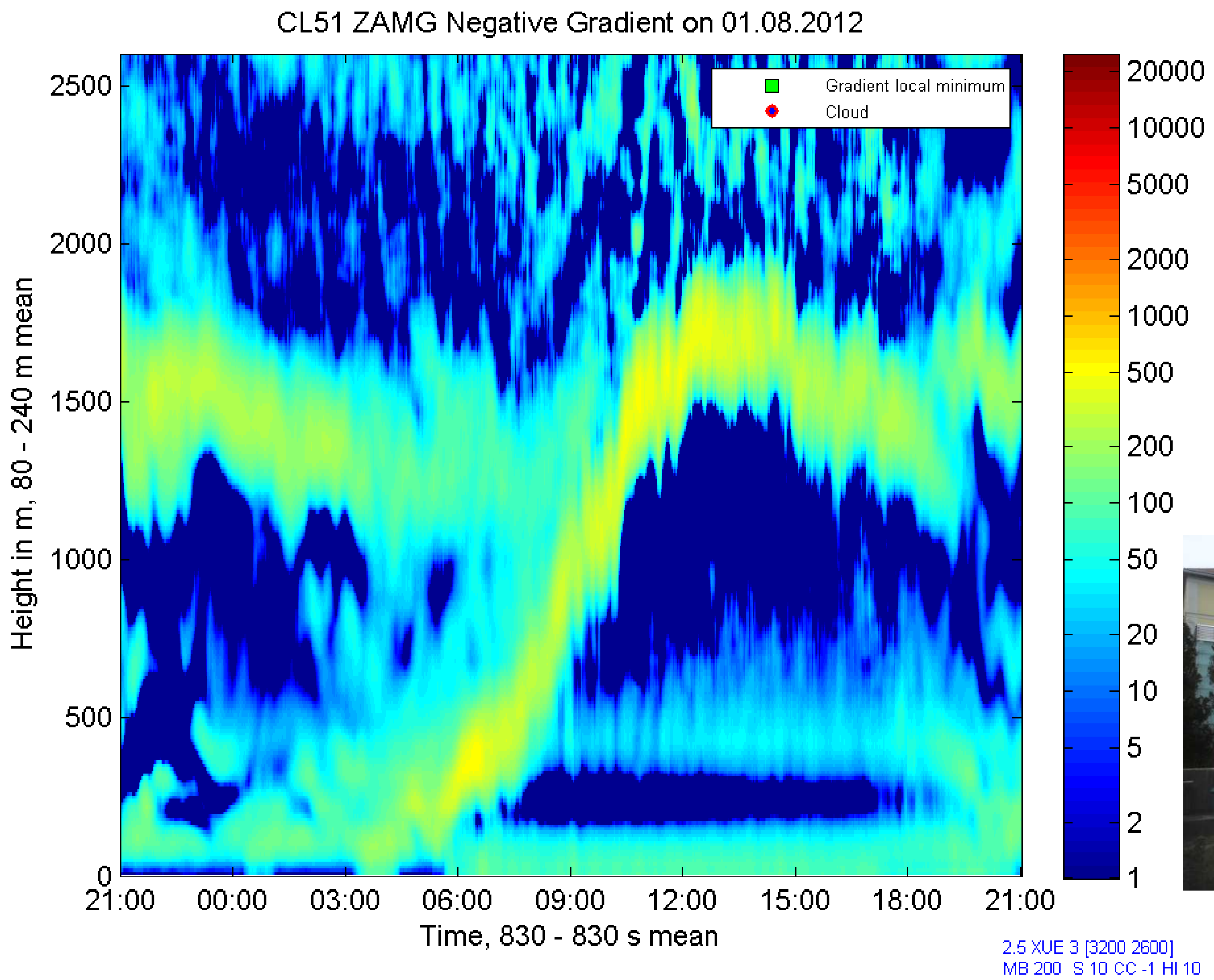
Negative gradient plot



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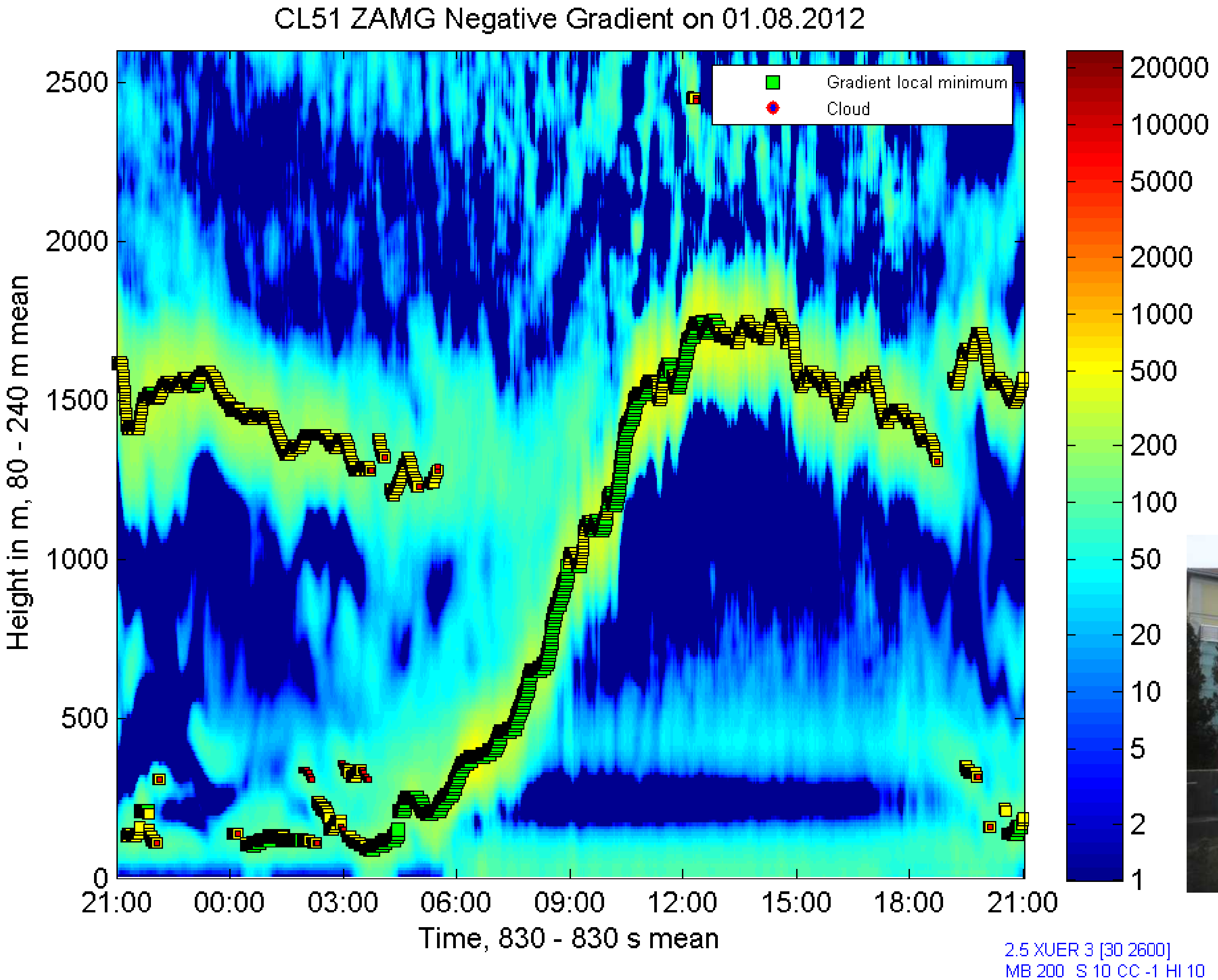
Pick gradient minima as layer tops



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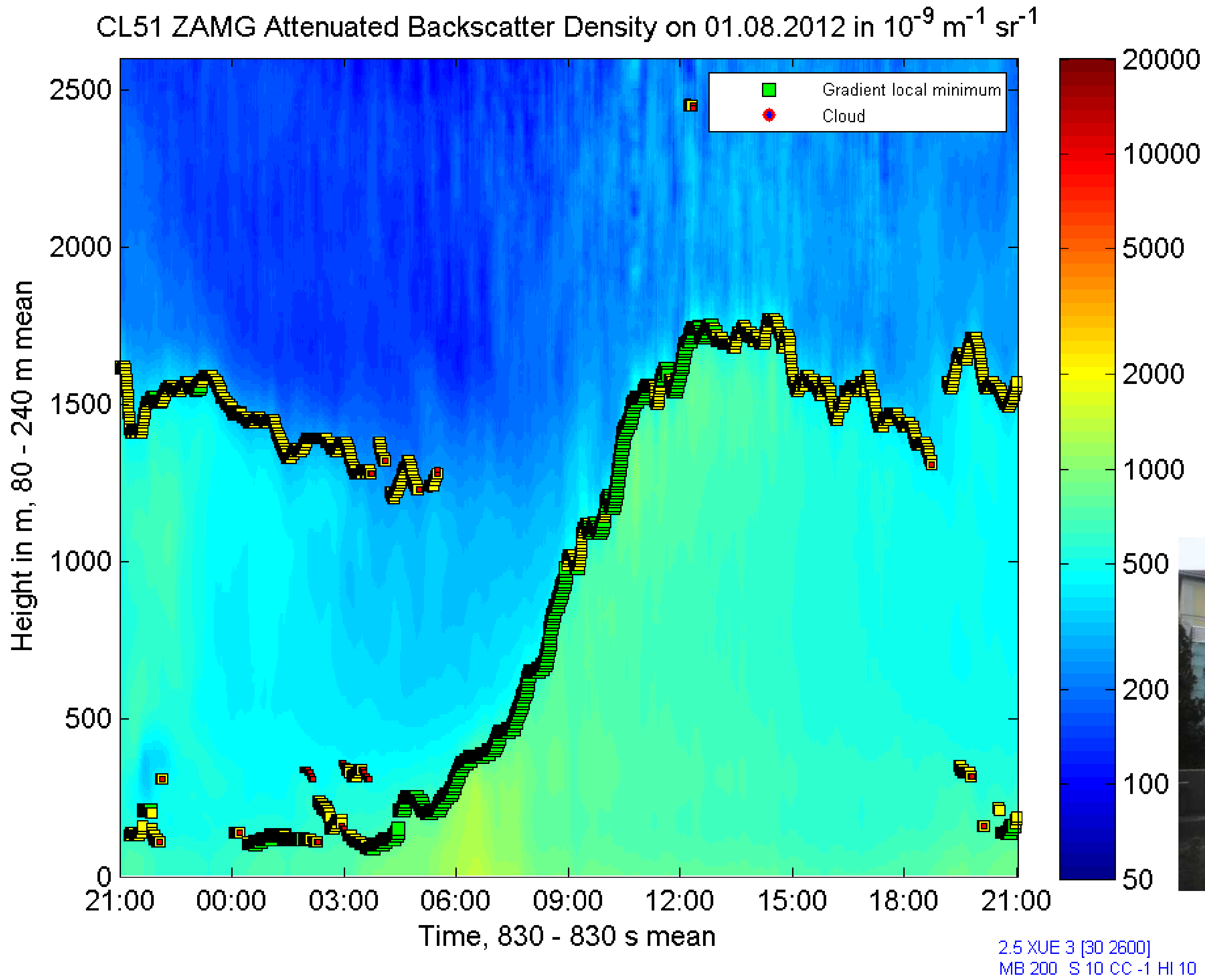
BL-VIEW algorithm reports up to 3 layers



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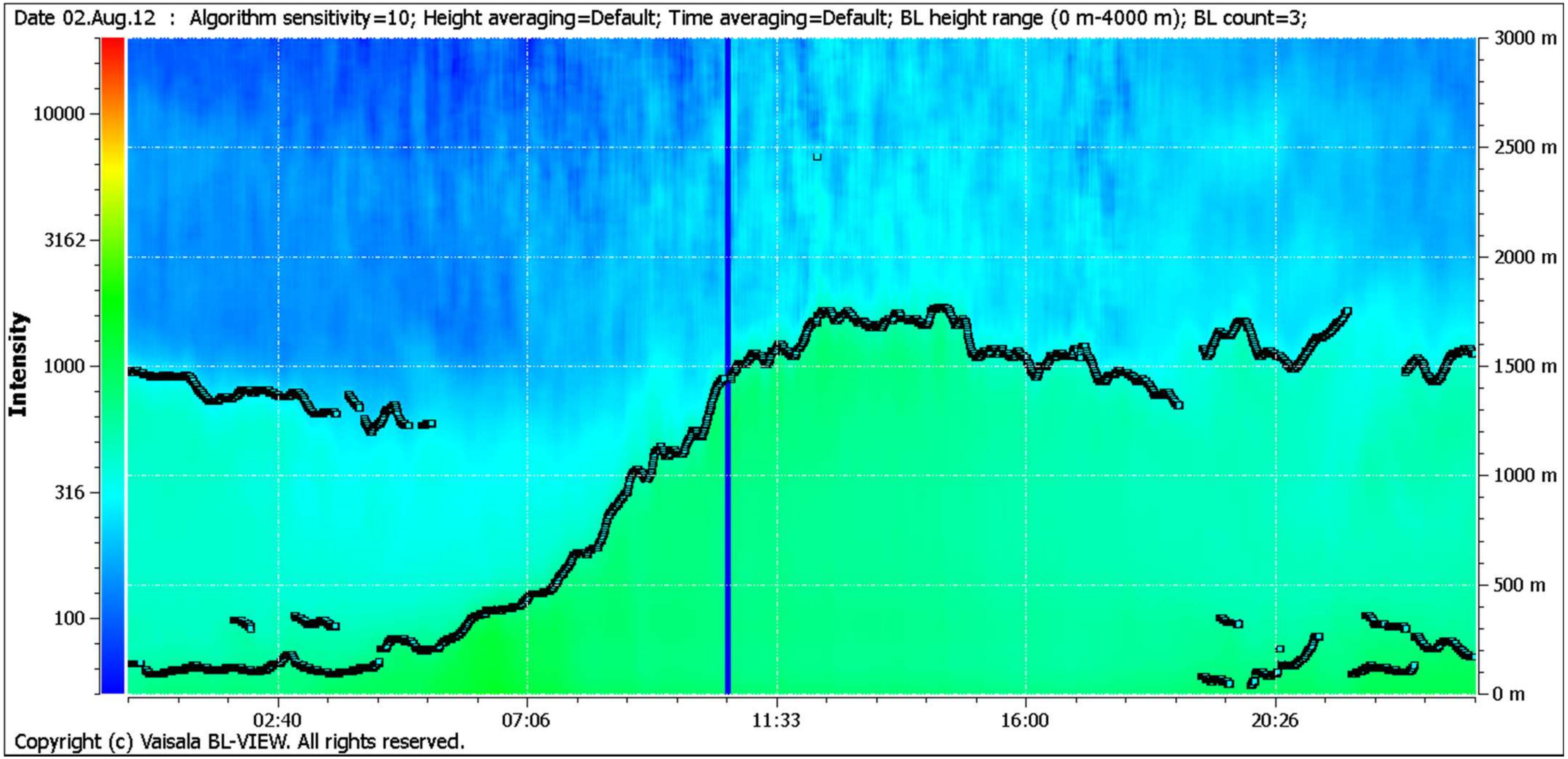
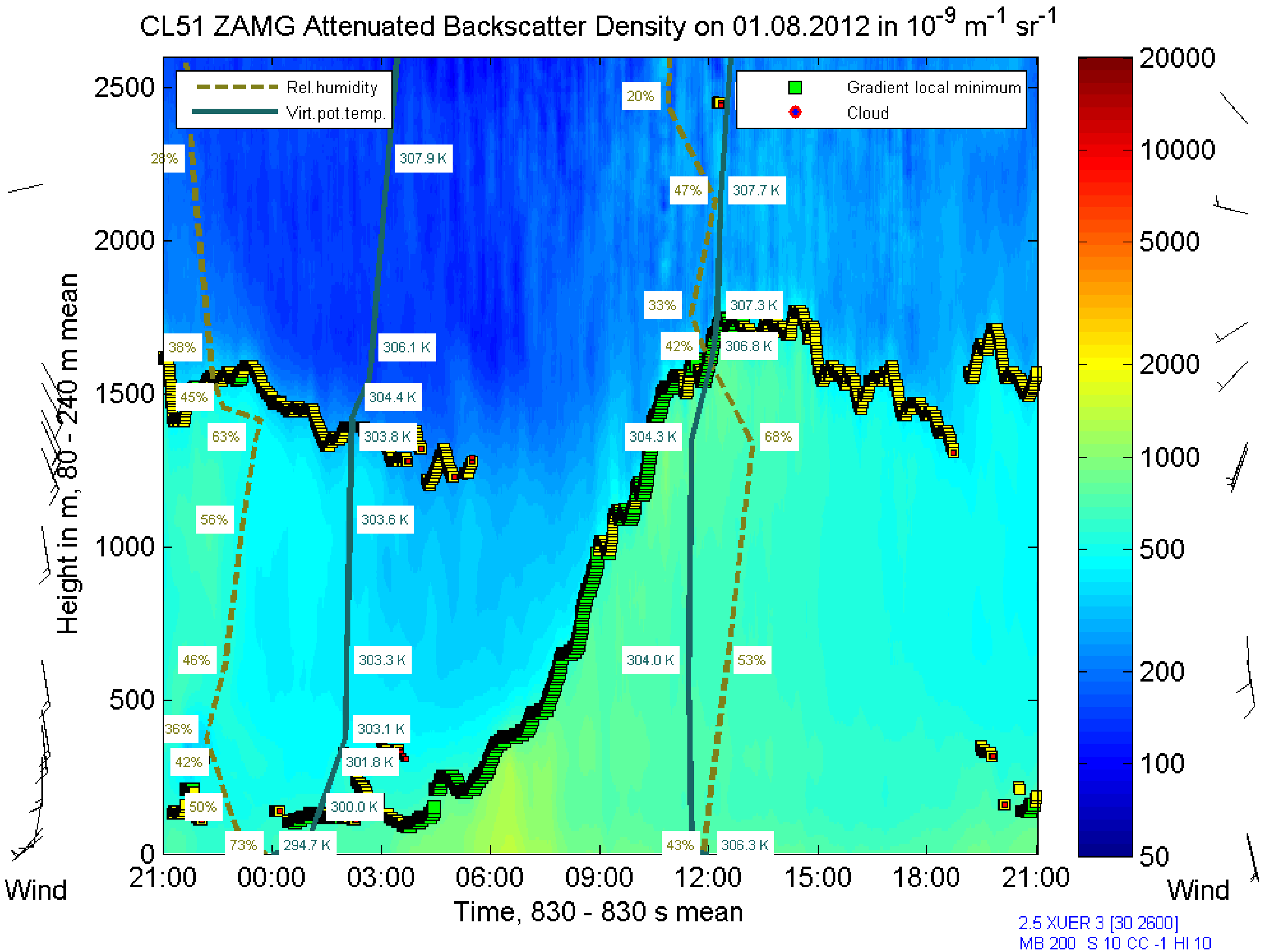
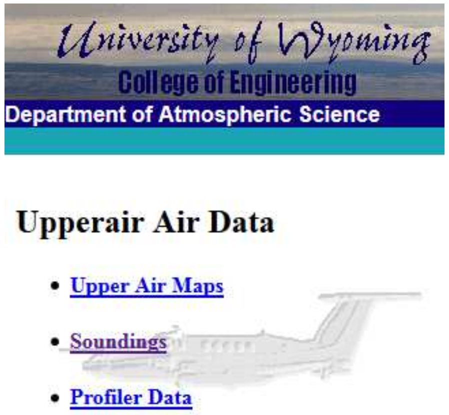
BL-VIEW algorithm reports up to 3 layers



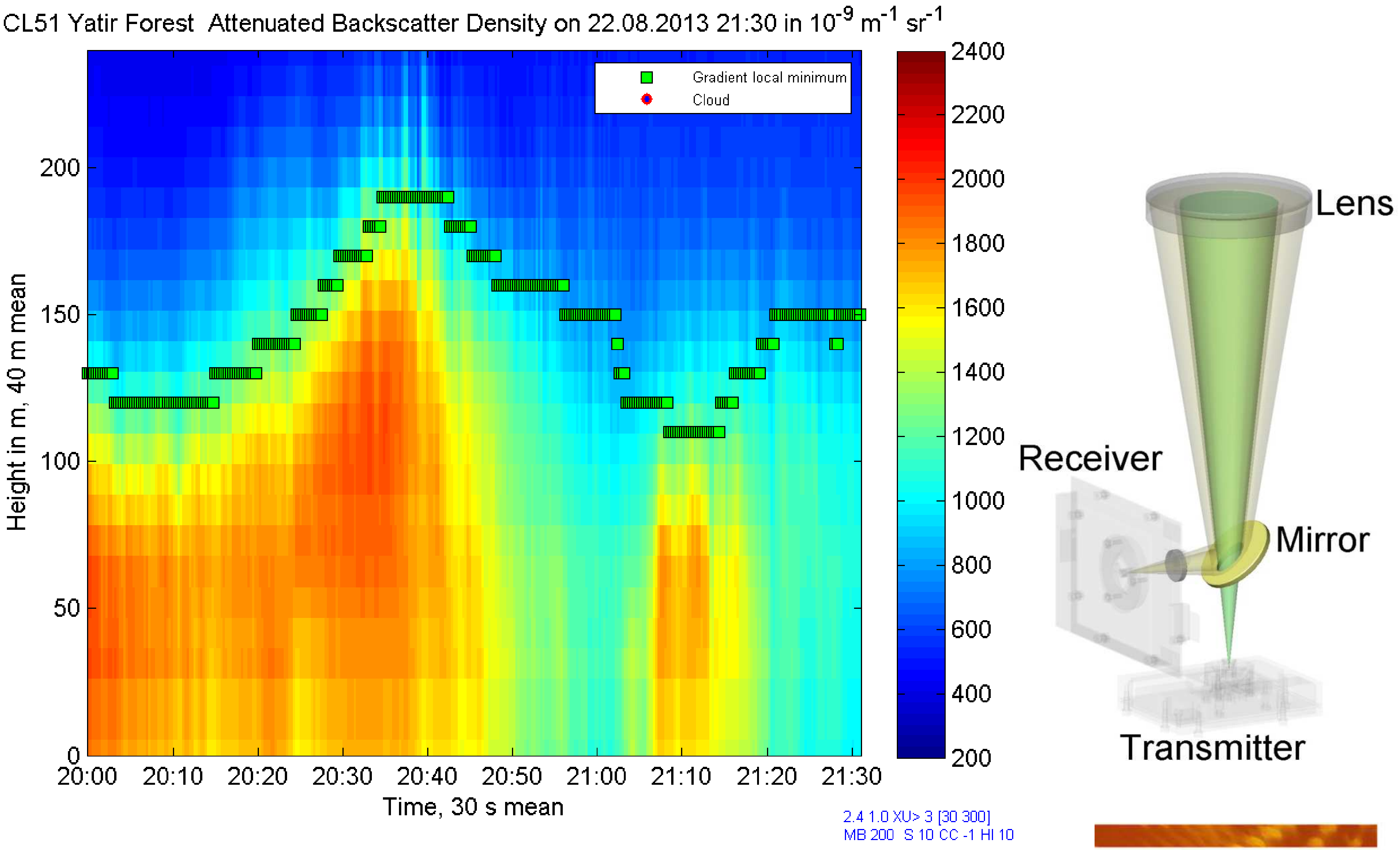
Presentation with the Vaisala SW product BL-VIEW

Radiosondes confirm layer tops





High res plot shows the good near-range behavior



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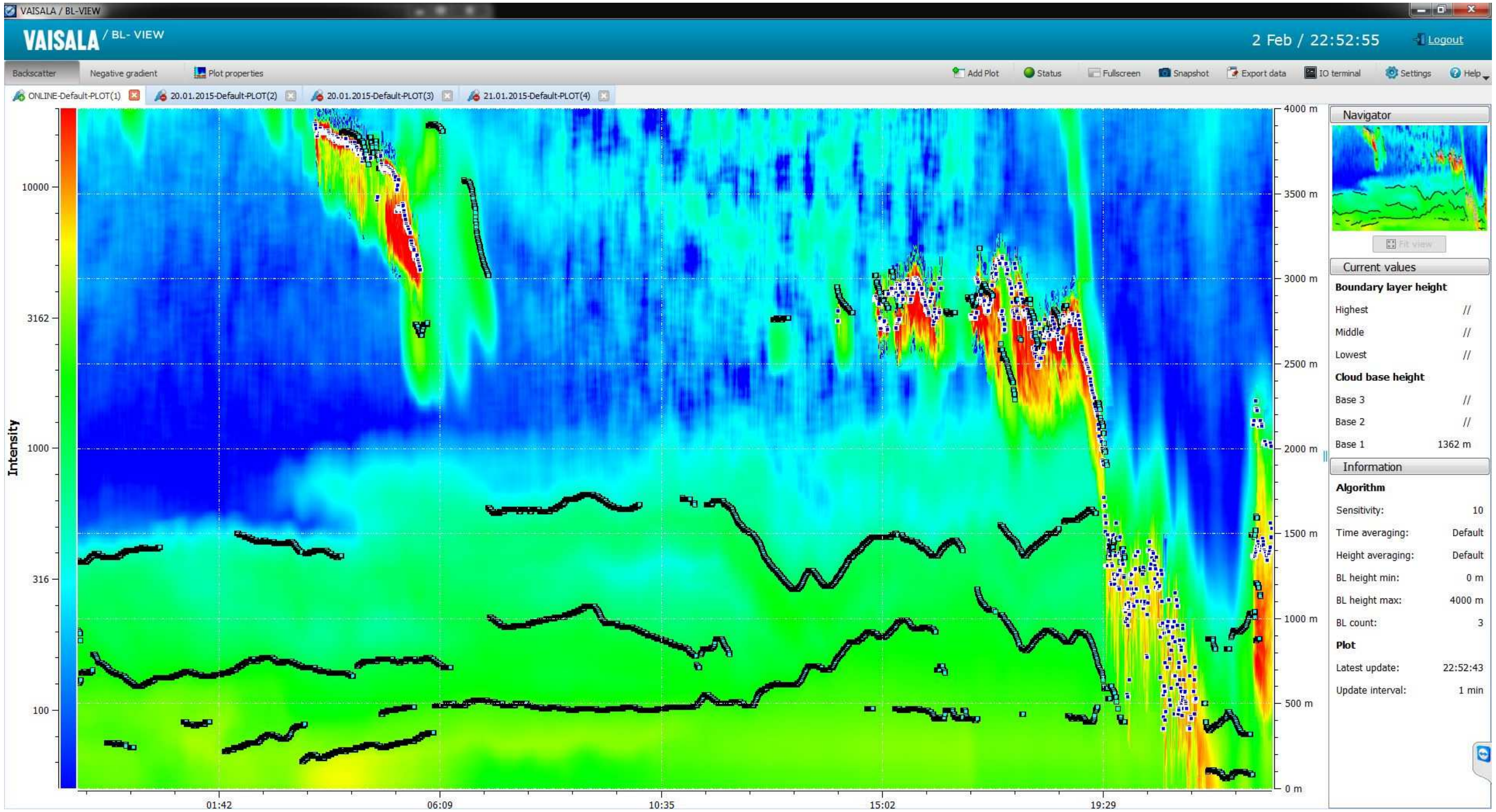
A CL51 with BL-VIEW is running in the Finnish Embassy in Beijing



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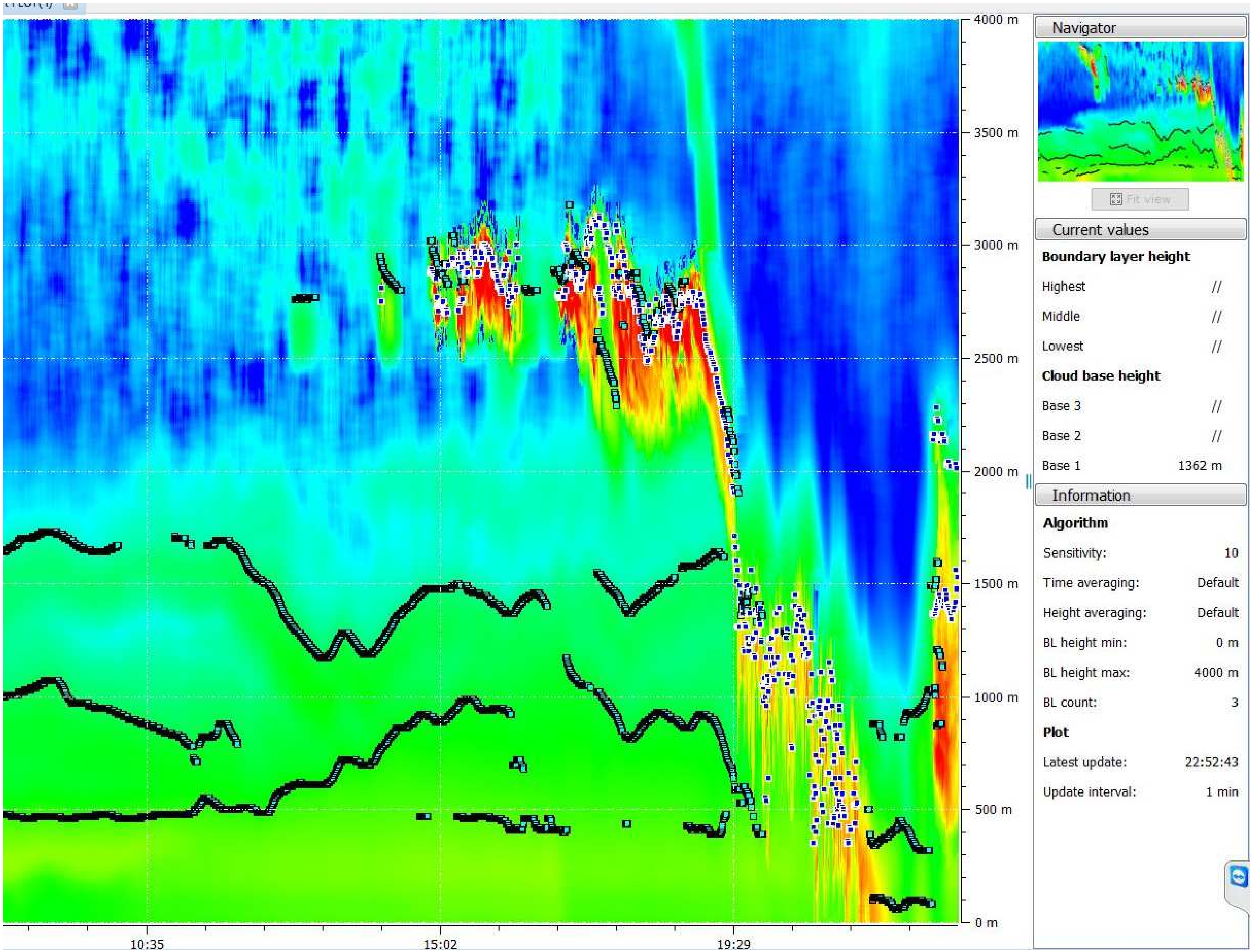
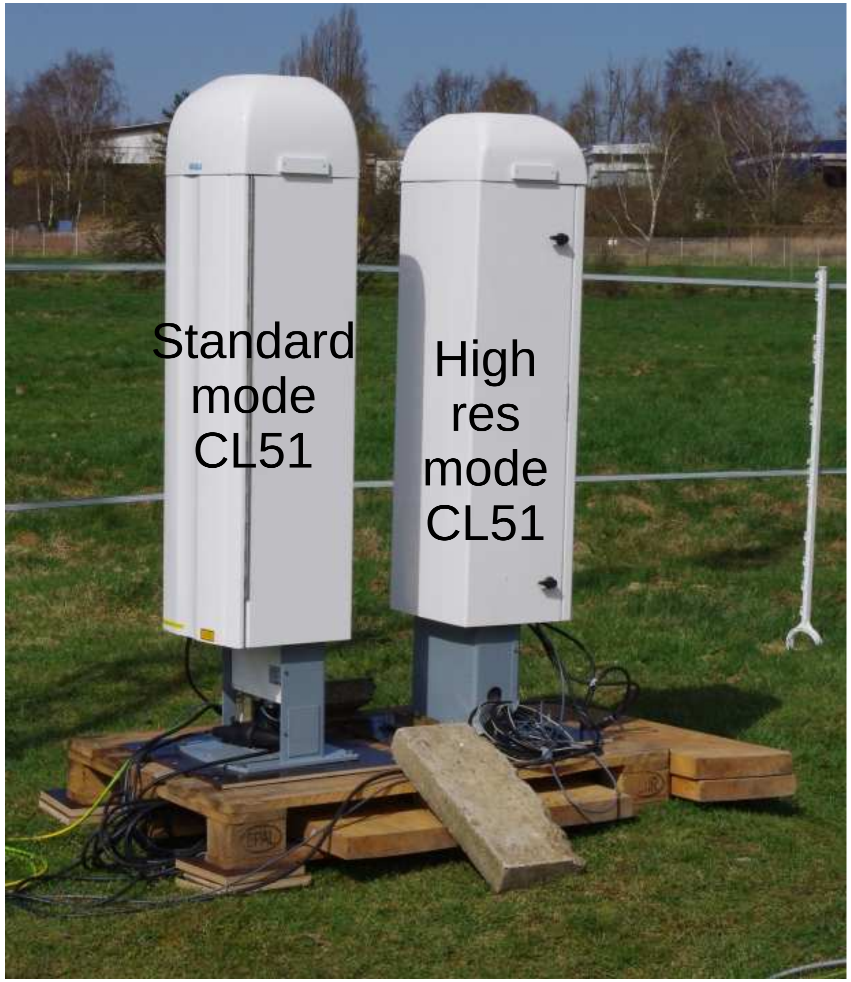


4000 m
3500 m
3000 m
2500 m
2000 m
1500 m
1000 m
500 m
0 m
10:35
15:02
19:29
Navigator
Fit view
Current values
Boundary layer height
Highest //
Middle //
Lowest //
Cloud base height
Base 3 //
Base 2 //
Base 1 1362 m
Information
Algorithm
Sensitivity: 10
Time averaging: Default
Height averaging: Default
BL height min: 0 m
BL height max: 4000 m
BL count: 3
Plot
Latest update: 22:52:43
Update interval: 1 min

Two co-located CL51 ceilometers at Hamburg Wettermast

	Standard mode	High res mode
PRF	8.192 kHz	8.192 kHz
Range resolution	10 m	10 m
Measuring range	7700 m	1800 m
Profile report interval	**16 s**	**0.5 s**



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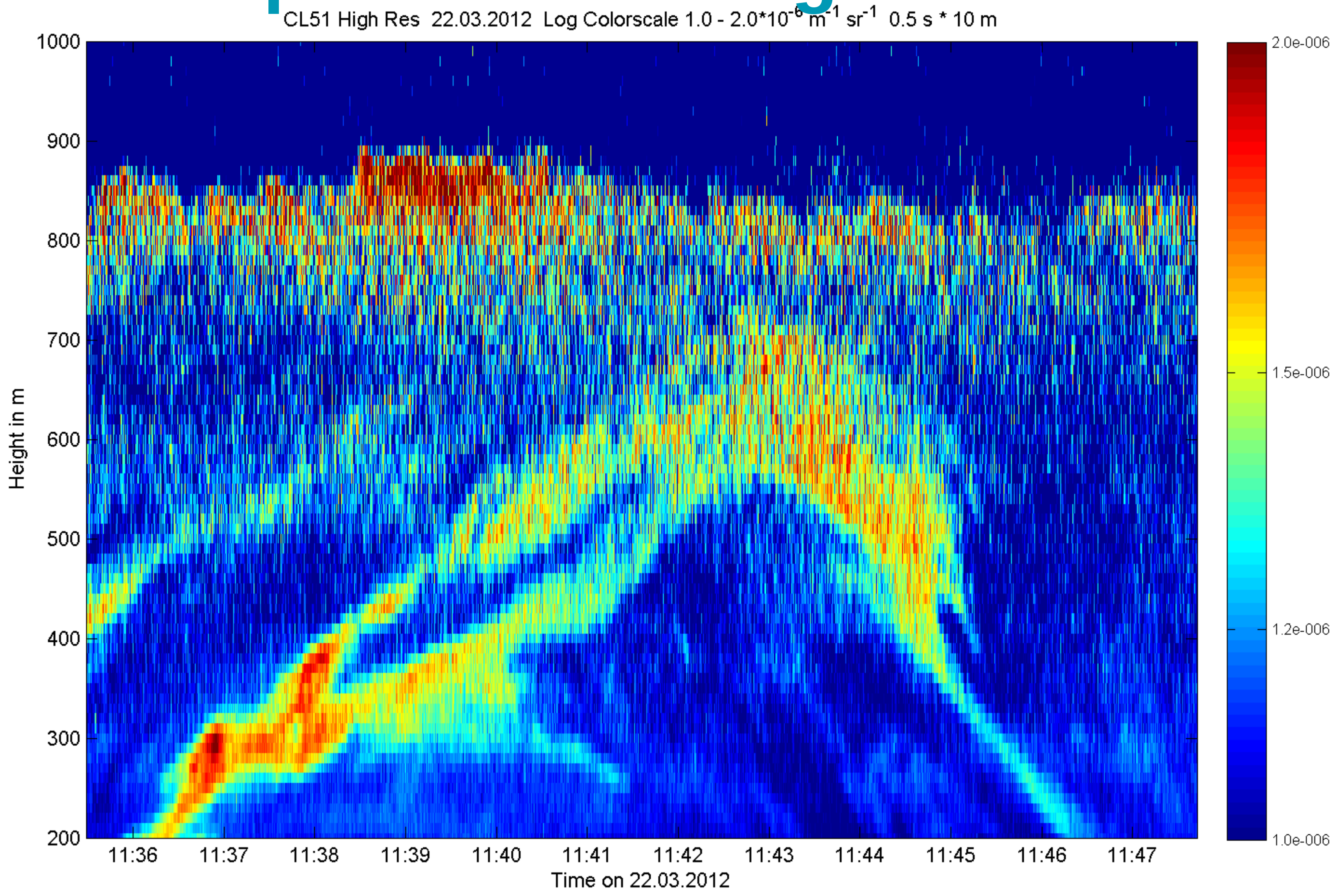
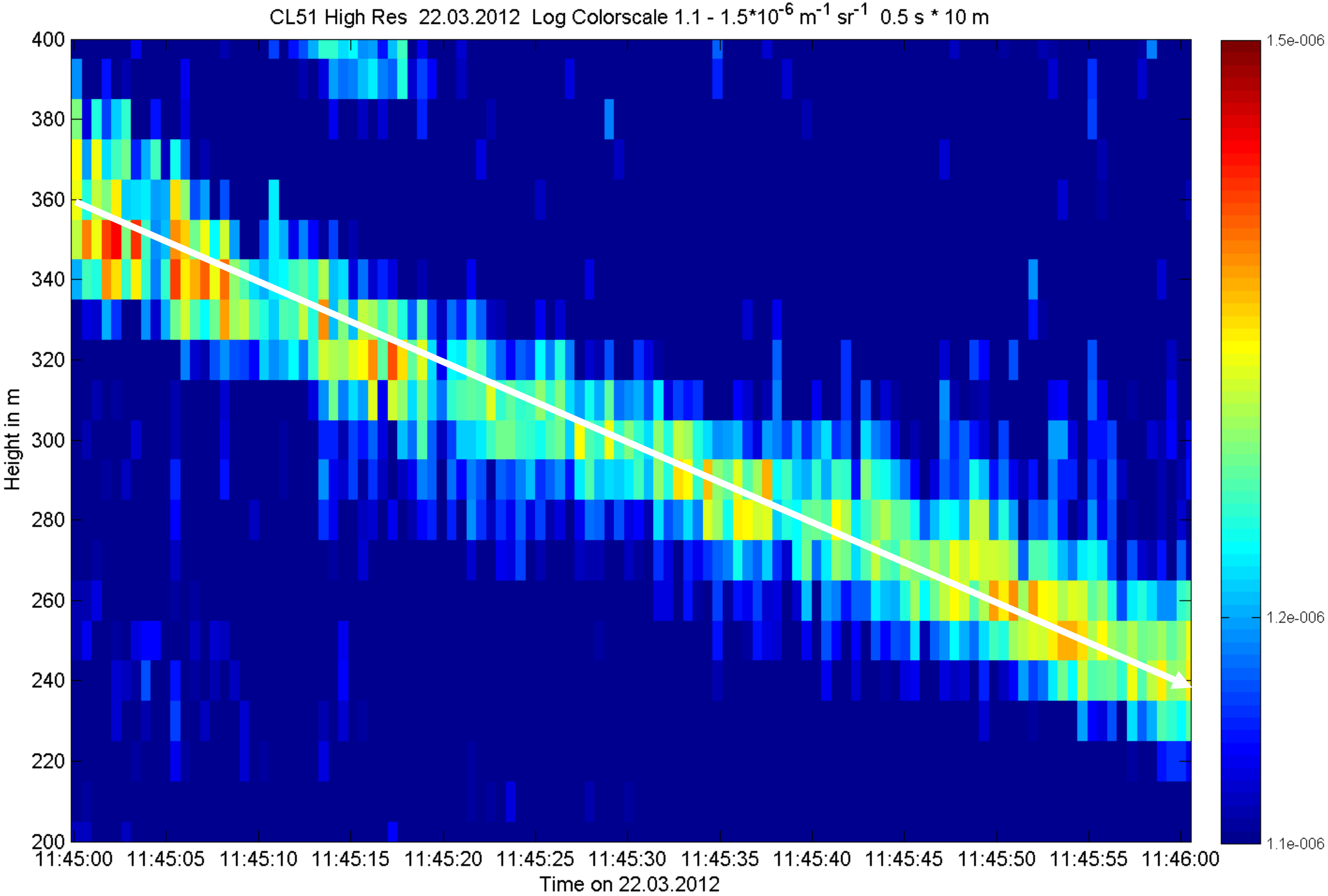
Investigation of rising and falling aerosol plumes with high res mode



This cooled bubble falls 120 m in 60 s



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  - Fabian Eder, Matthias Mauder

DTU Wind Energy
Department of Wind Energy

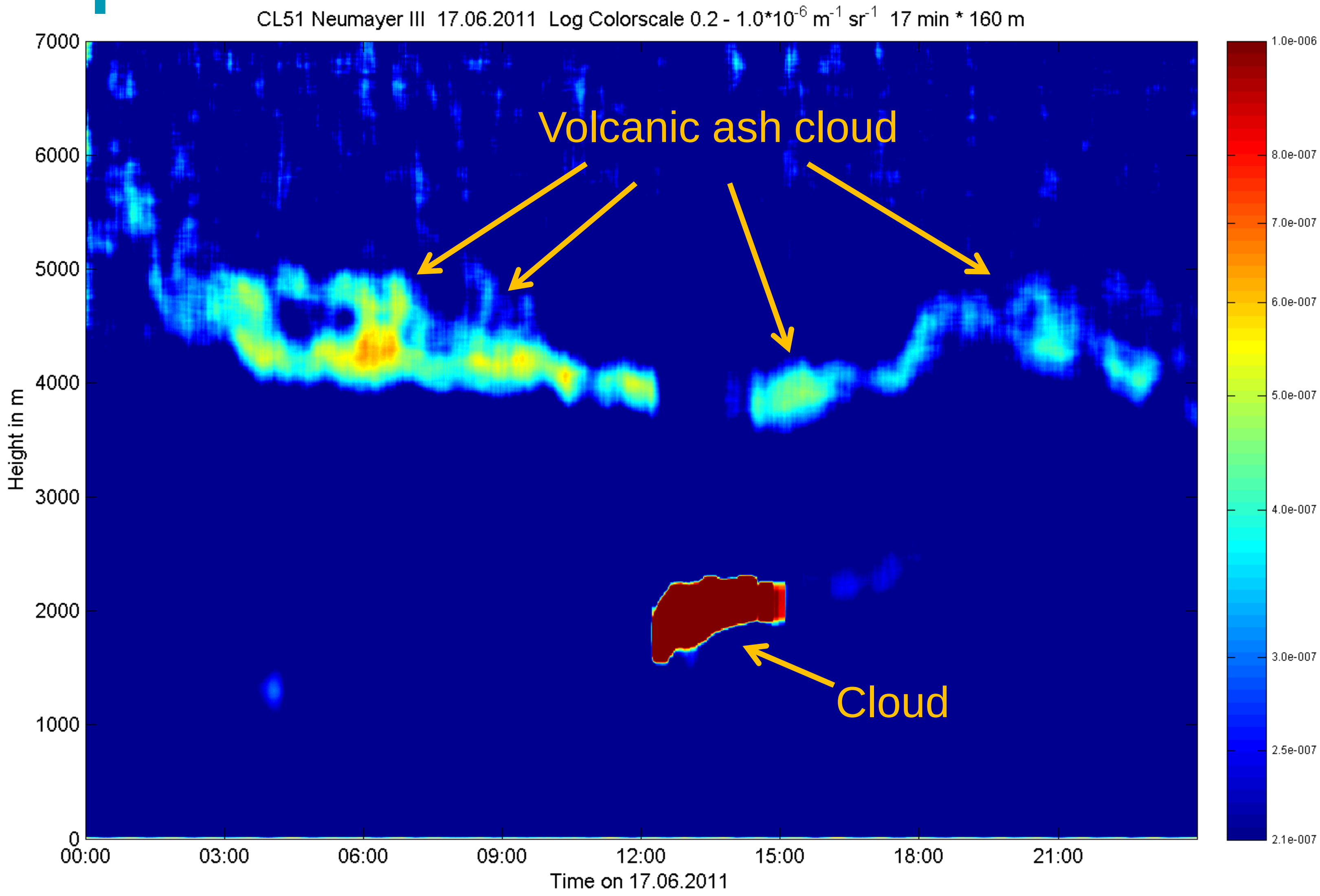
ZAMG
Zentralanstalt für Meteorologie und Geodynamik

KIT
Karlsruhe Institute of Technology

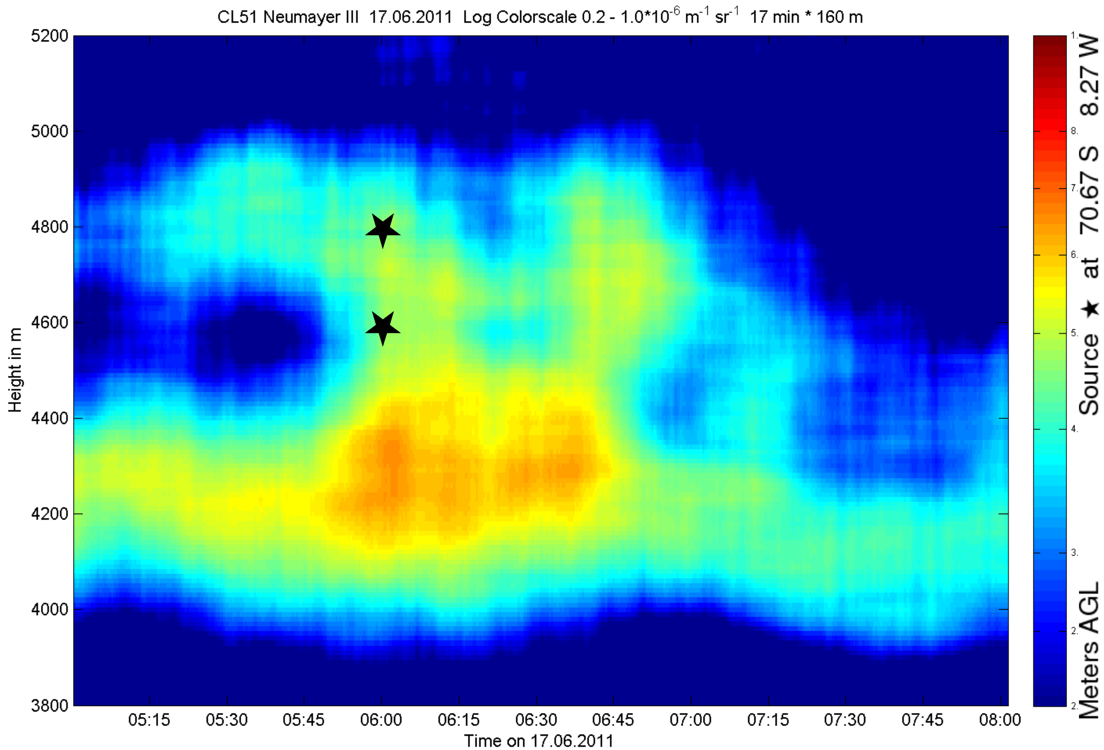
VAISALA

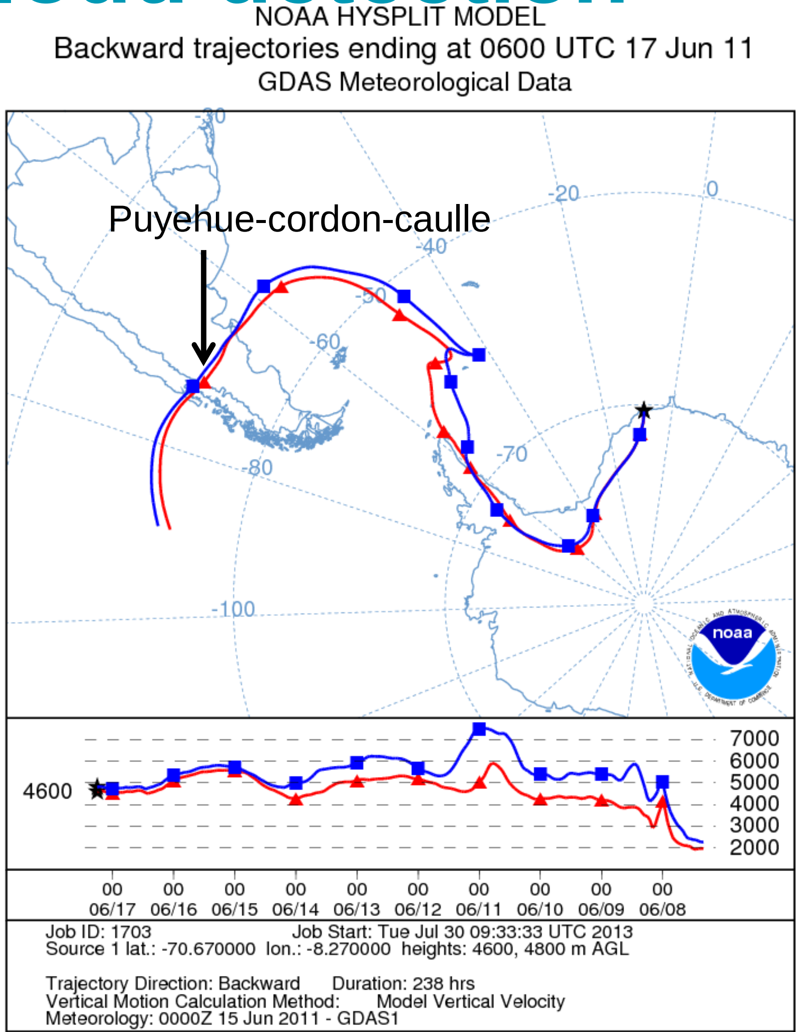
	CL31	CL51
Minimum range resolution	5 m	10 m
Typical range resolution for boundary layer scans	10 m	10 m
Minimum report interval	2 s	6 s
Typical report interval for boundary layer scans	16 s	36 s
Measuring range for cloud base detection	0 … 7500 m	0 … 13000 m
Backscatter profile range	0 … 7700 m	0 … 15400 m
Range for boundary layer fine structure profiling	0 … 4000 m	0 … 4000 m
Total height	1190 mm	1531 mm
Total weight	31 kg	46 kg
Weight of measurement unit	12 kg	18.6 kg
Laser type	InGaAs diode	InGaAs diode
Laser wavelength	910 nm	910 nm
Eye-safety class	1M	1M

Ash from the Puyehue-cordon-caulle eruption monitored over Antarctica

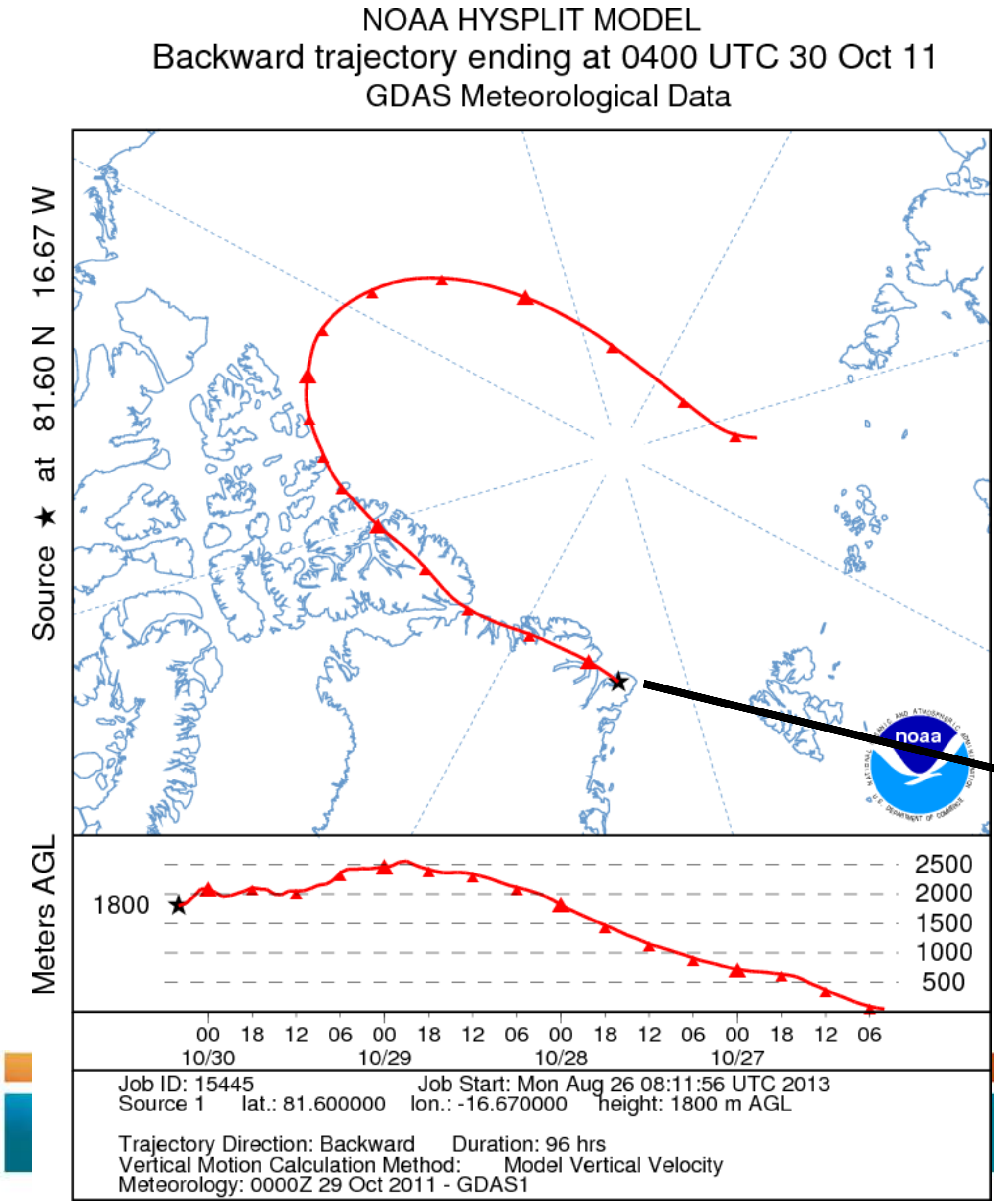


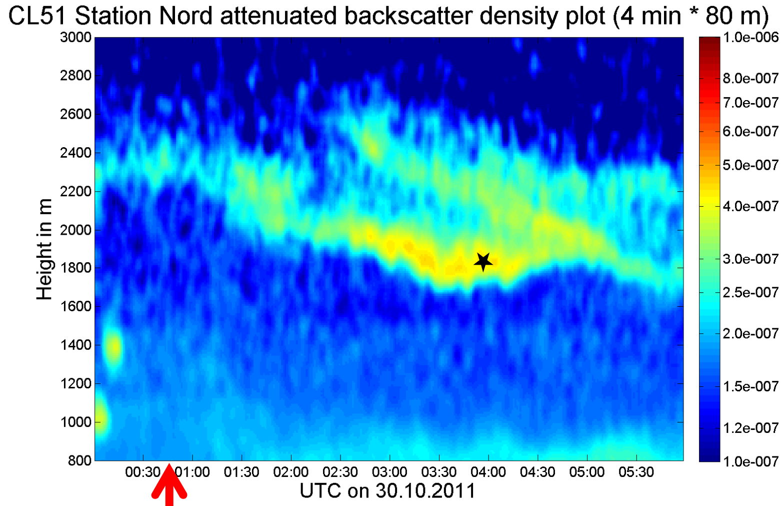
NOAA HYSPLIT backward trajectories confirm volcanic ash cloud detection

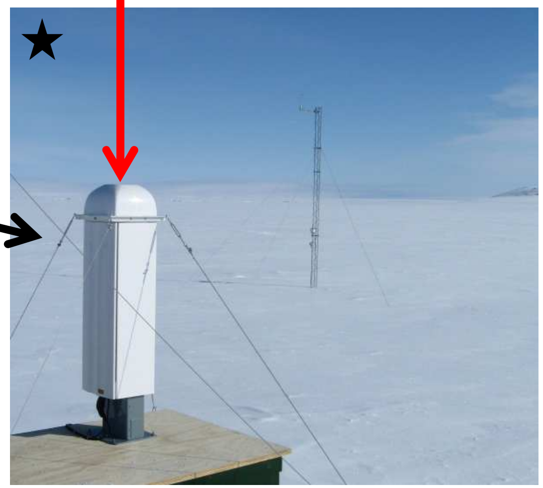




Arctic ice crystals aloft







Arctic ice crystals aloft