

Ceilometers/IR LIDAR backscatter and depolarization for AQ diagnosis and forecasting

Hypothesis: The near IR LIDAR backscatter signal from a ceilometer can provide a semi-quantitative measure of boundary layer mixing depth, fine PM concentration, and an indicator of cloud cover that can prevent surface radiative inversions.

Feb 2023 NW-Airquest Meeting

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Outline

- The problem
- Ceilometer/ lidar basics
- Data/web display
- Examples and Discussion
 - Stratus and rain
 - Depolarization and snow/ice
 - Wildfire smoke
 - Inversions

WA Ecology Grant to Prevent Non-Attainment (PNA)... (thank you ECY!)

The plan:

- Deploy ceilometers in two at-risk cities/areas.
- Monitor meteorological conditions for a year (focused on winter).
- Refine a description of the synoptics that allow for high winter-time PM.
- Identify predictive metrics, or model failures where improvement could be made

The problem:

- Many areas experience rapid increases in anthropogenic pollution in the night time hours, especially in the winter.
- Likely radiatively driven surface temperature inversion...
- Very shallow mixing depths, ~ 10s of meters...
- But we don't always get spikes on clear, nights...

So,

- Are inversions actually forming and there's just less emissions or other mixing?

Ceilometer basics:

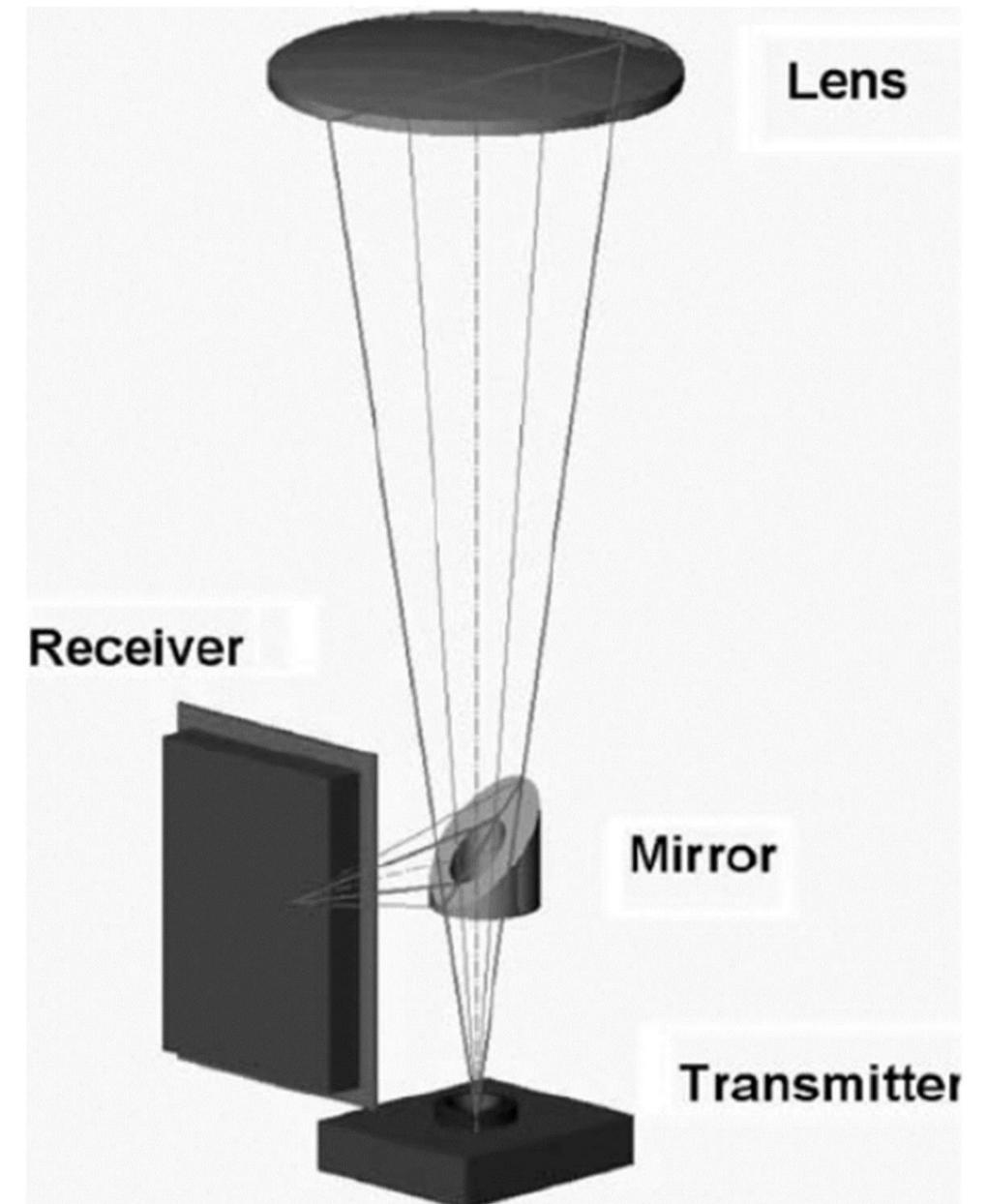
- Vertical pointing, fixed LIDAR, in the near IR (910 nm)
- For Vaisala CL-31: Short pulses (~110 ns), 1.2 uJ/pulse, at about 8 kHz, power averages about 12 mW
- Is significant backscatter for cloud drops and smaller particles
- Return signal is time-gated to assign a height(altitude) and many sequential measurements are averaged (typically 5 sec-5 min)
- Typical reported in units of $10^{-9} \text{ sr}^{-1}\text{m}^{-1}$ (*'nism'*)
- Clouds are 10,000 -100,000+, ambient PM pollution 300-3,000 ish

Ceilometer basics:

- Much structure in fine particles can be seen in 500-3,000 ish range
- Initial commercial purpose to measure the 'ceiling' – the cloud bottoms for aircraft
- Much research on reliably identifying the mixed layer height (mixing depth) – no clear winner yet
- NWS ASOS has 900+ throughout the U.S. – work in progress to make it available
- A few other non-NWS ceilometers are in the Unified Ceilometer Network - <https://www.ucn-portal.org/>

Overlap?

- Low altitude sensitivity is tough, overlap and crosstalk challenges
- Vaisala CL-31, -51, and -61 have co-linear laser, lens, and mirror, so about as good as currently possible
- Most ceilometers designed for detection at > 100m, but some claim sensitivity 50-100m
- Surface radiatively driven inversions can be only a few 10s of meters, with minimally vertical growth, but can strengthen (temps drop)



PCAA 'network':

1. Have had a CL-31 at Tacoma for ~ 10 years
2. Just added a CL-31 in Darrington, and -61 in Marysville
3. Setup website to show data in real-time
4. Collecting data for ECY PNA grant research
5. Happy to add/support/assist anyone else for displaying...



10:32

2023-01-11

Tacoma South L

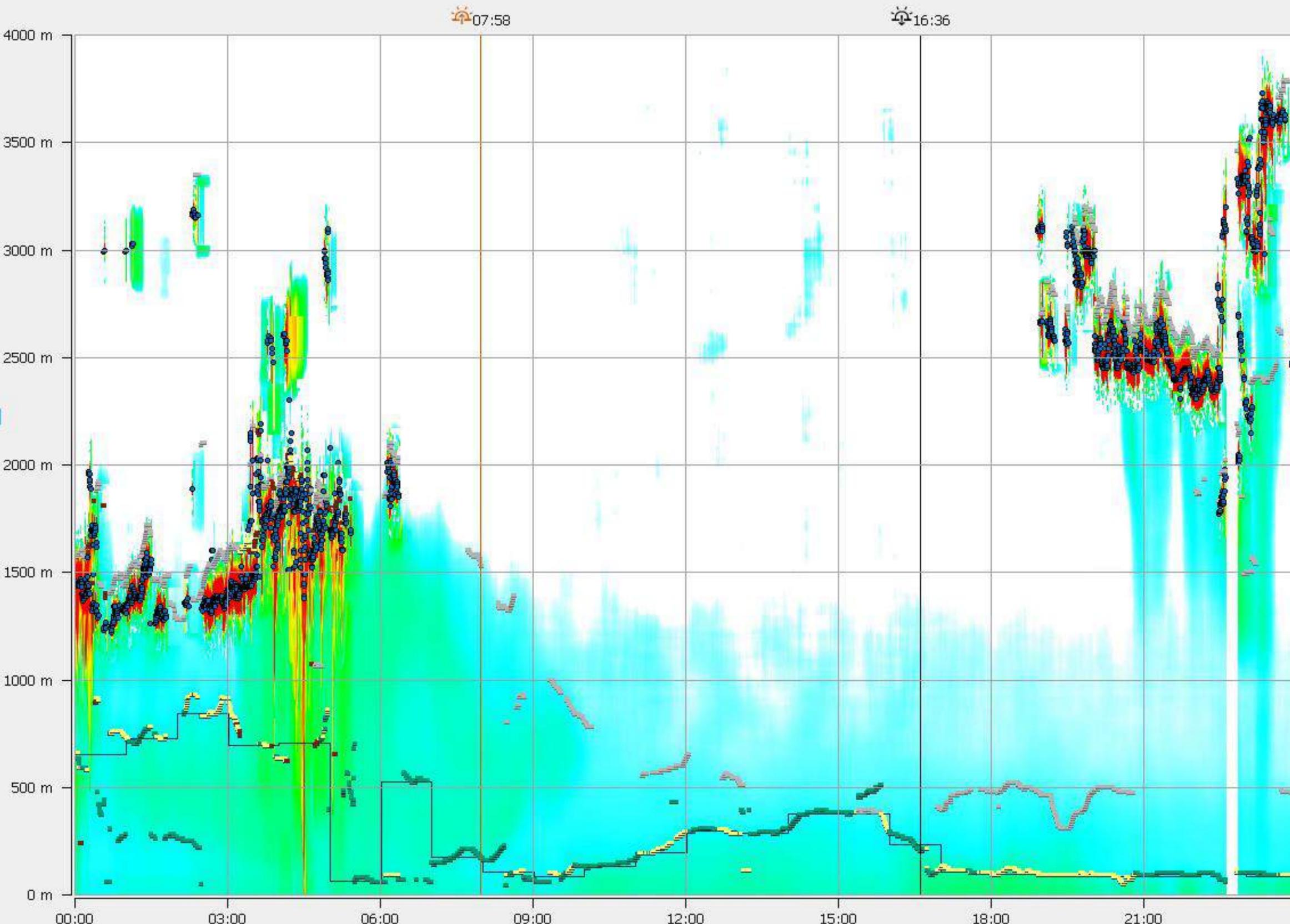
Vaisala Default Display:

Tools

Help

System

Live-Default Live-PSCAA 10.01.2023-Default



Add Plot

Data

MLH data Profile data

4000 m 7700 m

15400 m

Legend

Layer height

Mixing layer

1h average

Elevated layer 1

Elevated layer 2

Cloud base height

Base 1

Base 2

Base 3

Intensity

Intensity

View

Backscatter Negative gradient

100 1000 10000

Navigator

Fit view

Information

Algorithm

Method: Merged

Ceilometer data display tools

1. Select ceilometer
2. Select height
3. Hit “Switch Inst/...”
4. “Toggle” will toggle between backscatter and depolarization or smoothed backscat
5. “-1 Day” and “-2 Day” will show older

PSCAA ceilometers: Select instrument and height...

- Tacoma S. L CL-31
- Darrington CL-31
- Marysville CL-61
- 15 | 7.7 km
- 4.5 km
- 1.1 | 0.6 km

-2 Day (UTC)

-1 Day (UTC)

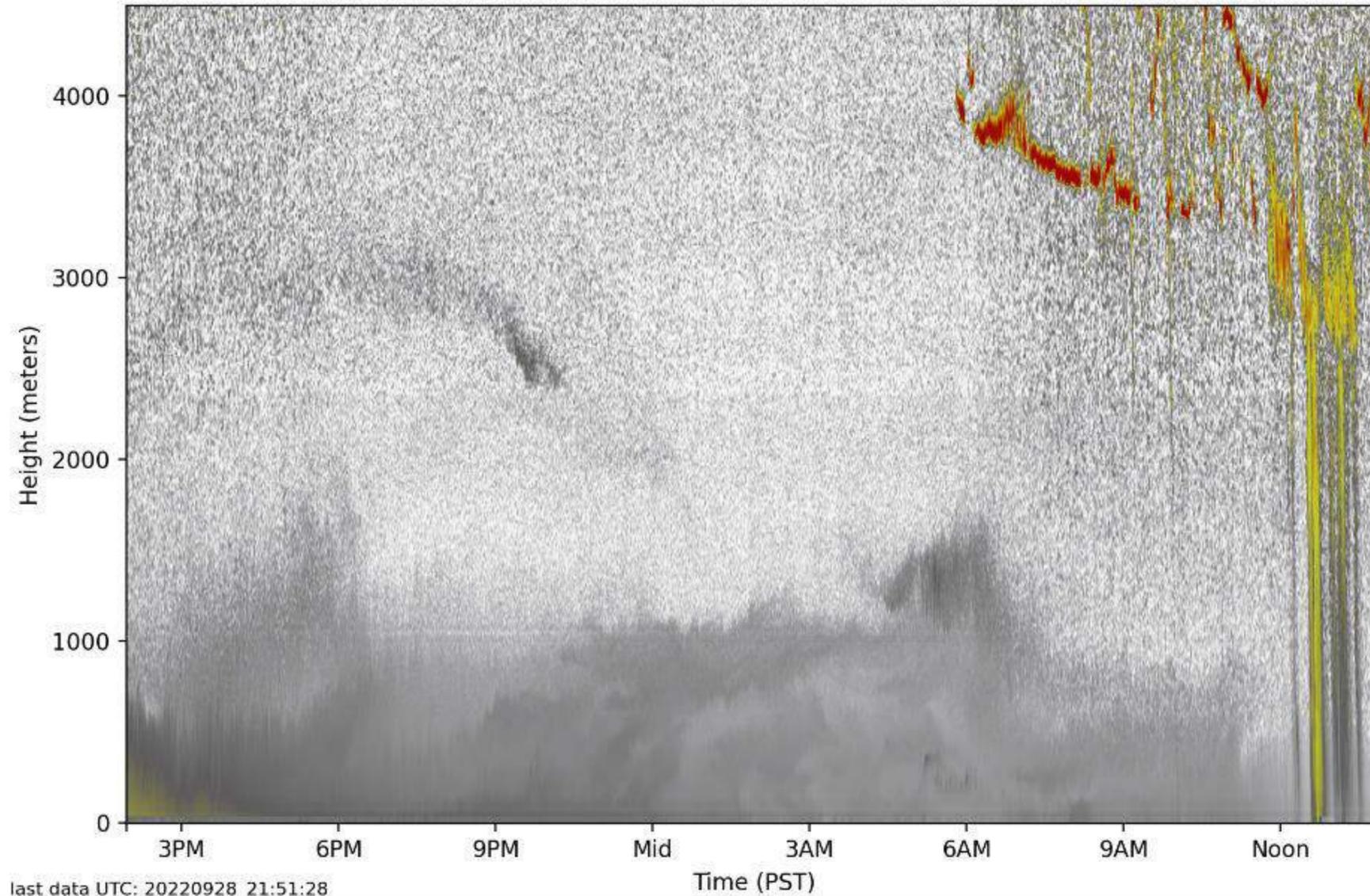
Switch Instr/Height Show Last 24-hours

Toggle bscat/depol/smooth

dr3145bs.png

time generated:13:56:02

Darrington Ceilometer Raw Backscatter for 20220928



last data UTC: 20220928_21:51:28

Ceilometer data display tools

1. More info in **About + Downloads**
2. Note graphic name in upper right above the figure
3. Can download archived images using web address, date, and name...

PSCAA ceilometers: Select instrument and height...

- Tacoma S. L CL-31
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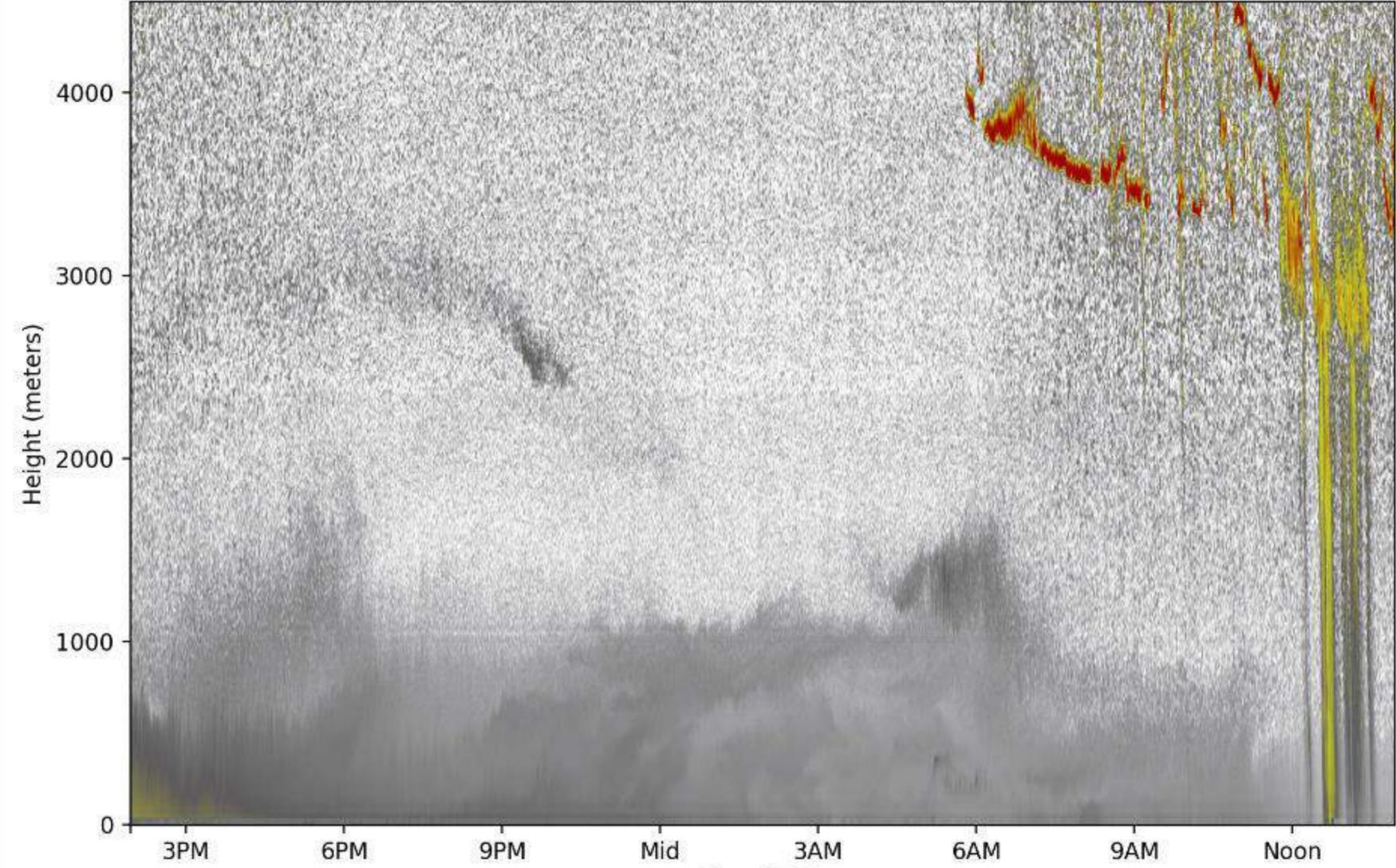
Switch Instr/Height Show Last 24-hours

Toggle bscat/depol/smooth

dr3145bs.png

time generated:13:56:02

Darrington Ceilometer Raw Backscatter for 20220928



last data UTC: 20220928_21:51:28

About + Downloads

Ceilometer data display tools

1. More info in **About + Downloads**
2. Archive images retrieval address
3. Other notes
4. I can add other ceilometers, but must have internet connection and be able to run a script in either Python or Powershell

PSCAA ceilometers: About & Downloads

Use notes:

- after changing instruments or heights, you must press "Switch Instr/Height Show Last 24-hours" to switch
- after you have switched instruments/heights, then you can go back in time with the -1 day, -2 day buttons

Archived images are available for download using addresses formed like this:

pscaa-ceilometerimages-public.s3.us-east-2.amazonaws.com/YYYYMMDD/iiiihhtt.png

where: *YYYY* is year, *MM* is month (numerical), *DD* is day

iiii is the location and instrument: *dr31* is Darrington CL-31, *mv61* is Marysville CL-61, *sl31* is Tacoma South L CL-31

hh is the height: *11* is lowest 0.6 km (-31) or 1.1 km (-61), *45* is about 4.5 km, *mx* is maximum: 7.7 km (-31), 15 km (-61)

tt is the data type: *bs* is backscatter, *dp* is depolarization, *sm* is smoothed backscatter

The corresponding image string is shown just above each image to the right

Other notes:

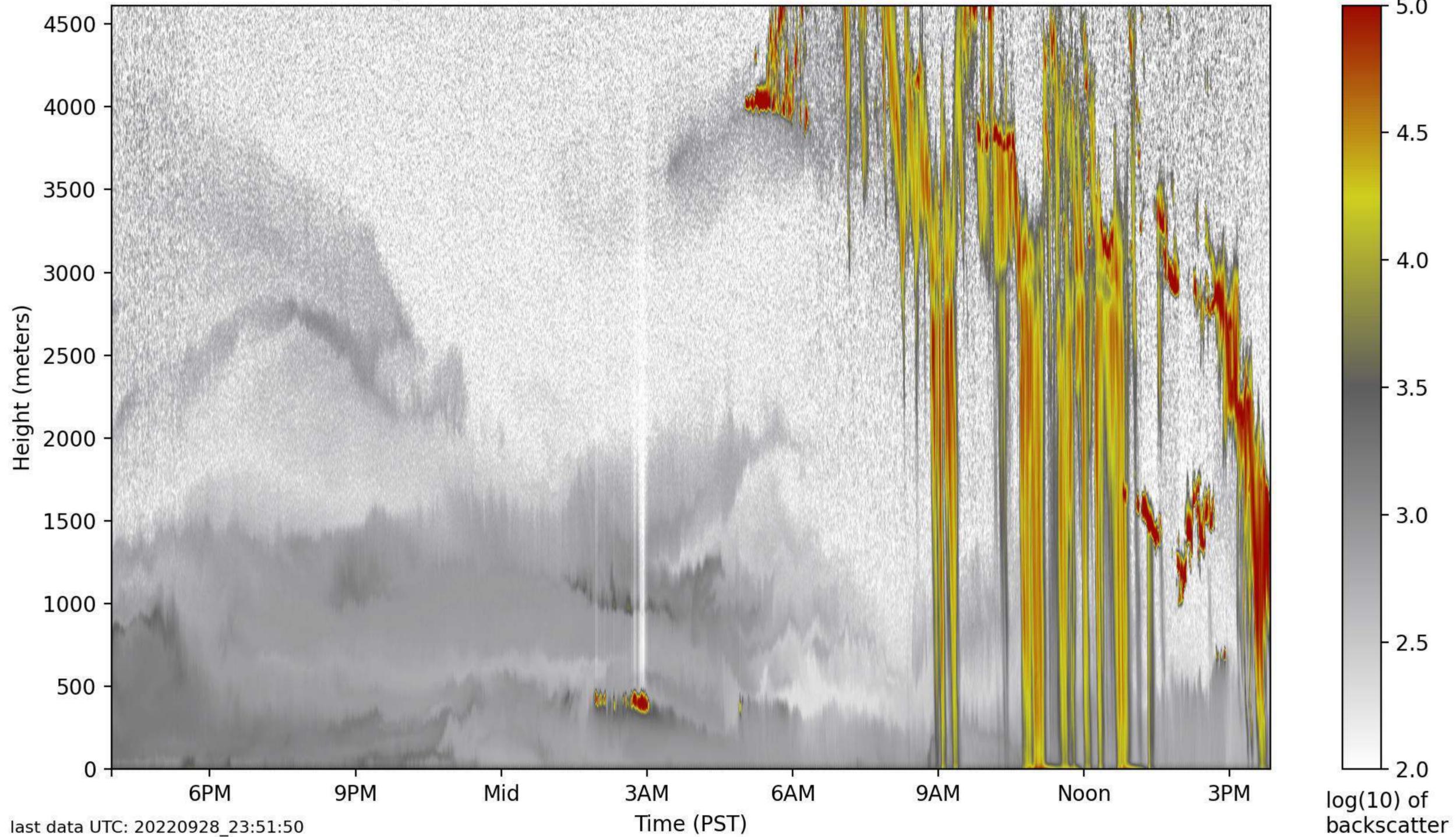
- depolarization is only on the CL-61
- smoothing is only done for CL-31s for mid and upper heights
- the depolarization signal is screened (out) for backscatter less than ~2.5 on the log(10) scale
- the image archive begins on about 2022-09-08
- Darrington data begin on 2022-09-24

last updated 2022.09.26

questions, comments? contact: phil.swartzendruber at cleanairpugetsound dot net

time generated:15:58:02

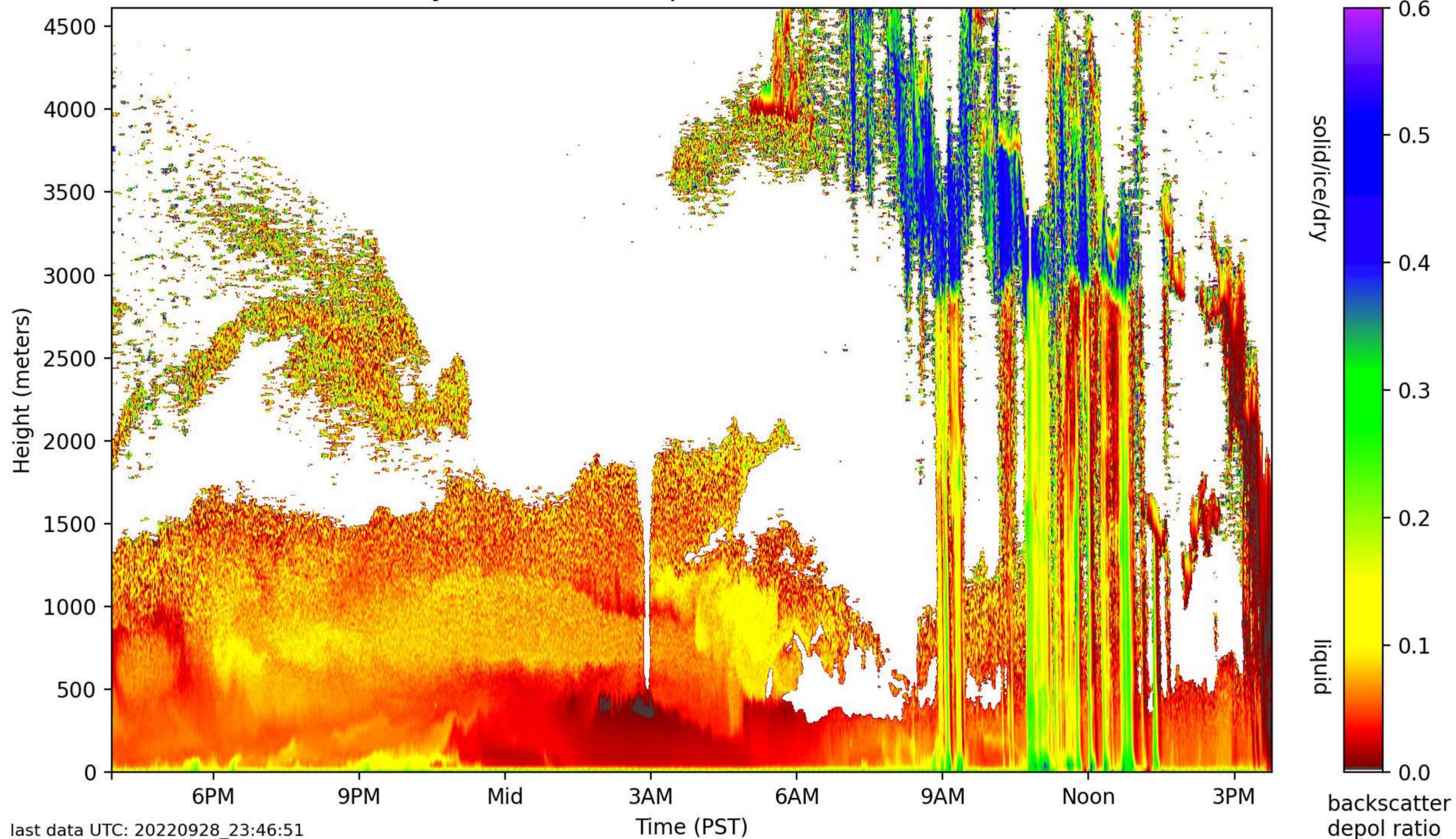
Marysville CL-61 Raw Backscatter for 20220928



last data UTC: 20220928_23:51:50

time generated:15:54:10

Marysville CL-61 Depol Ratio for 20220928

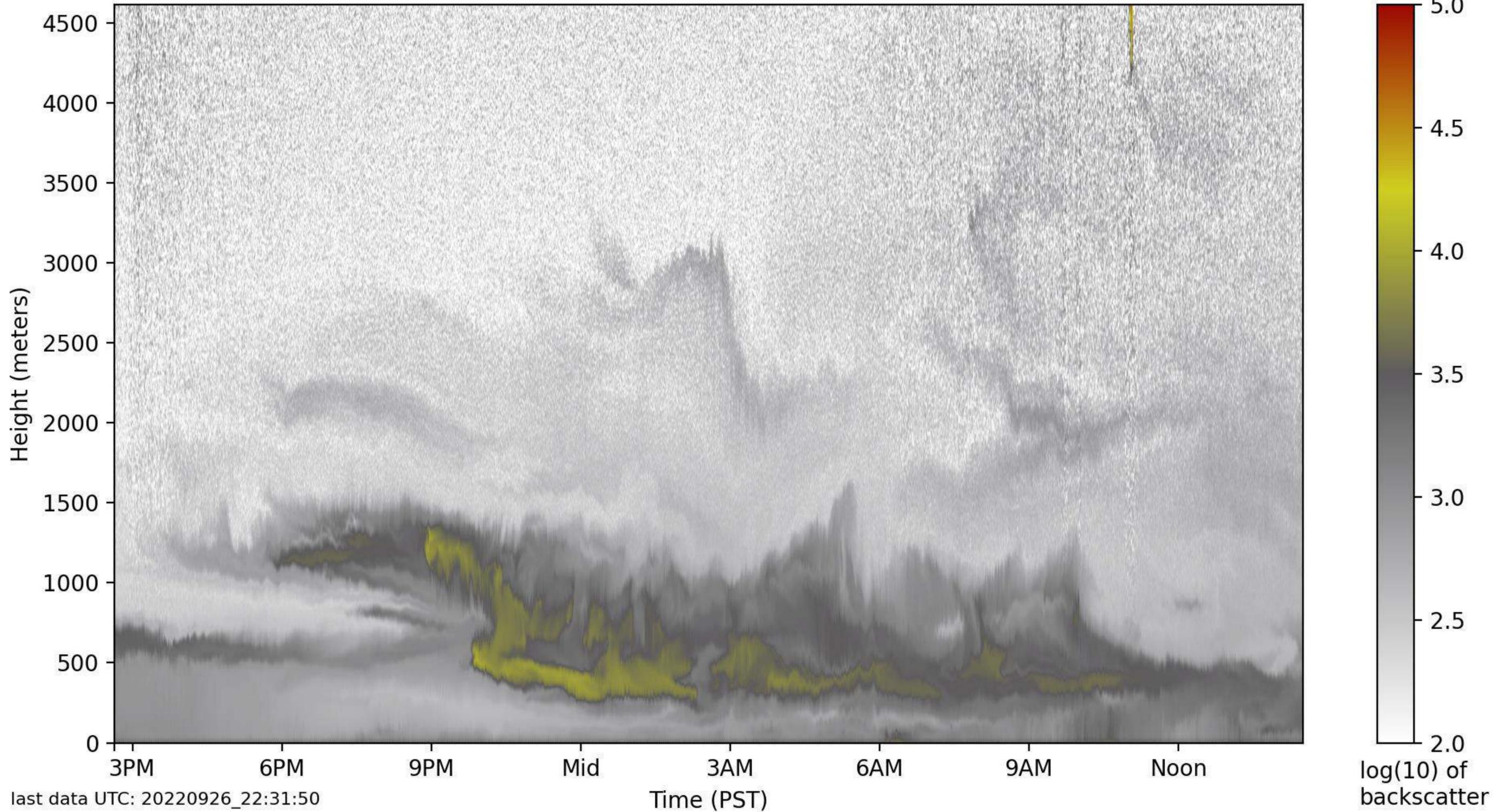


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Wildfire Smoke...

time generated:14:38:02

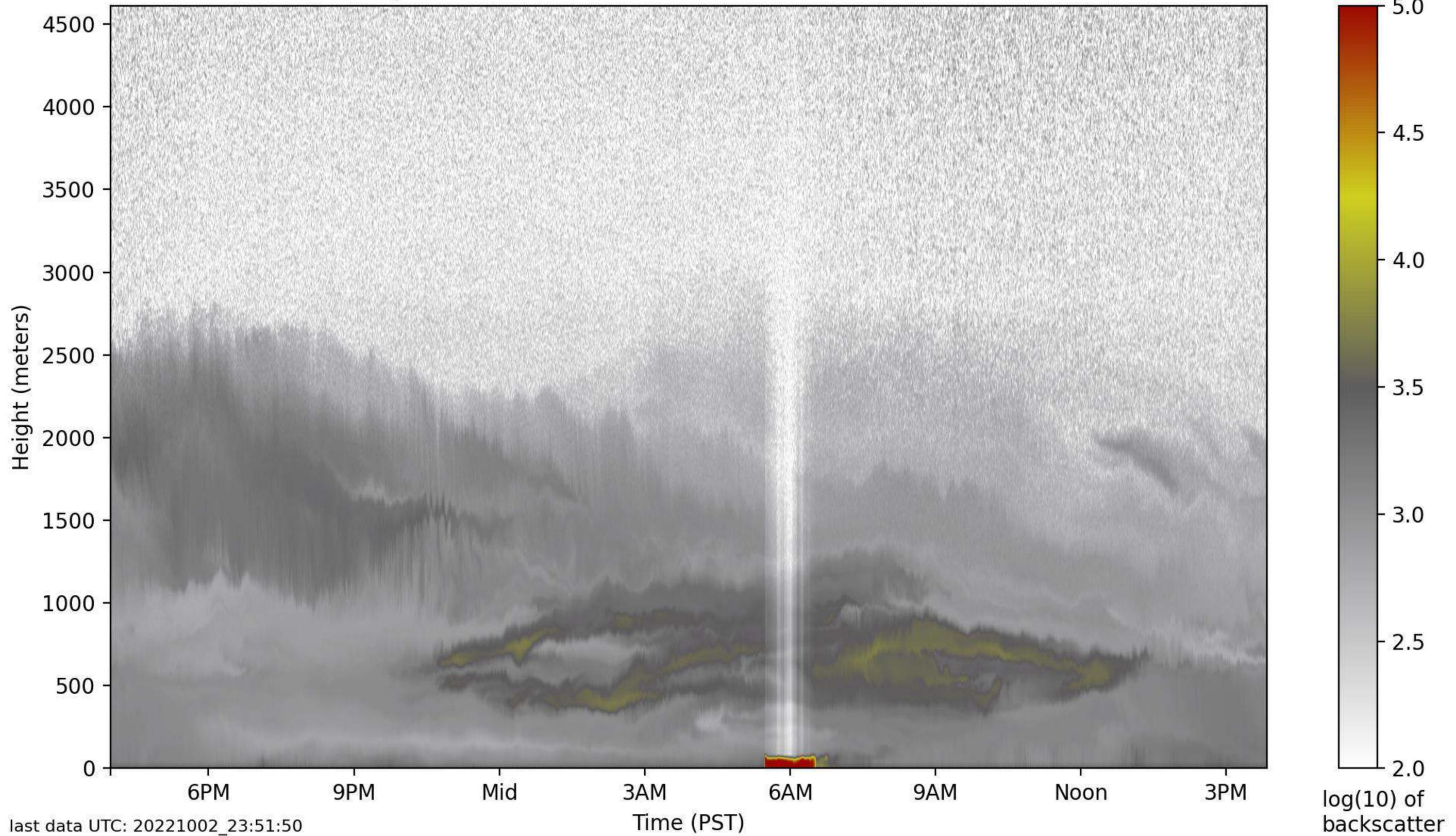
Marysville CL-61 Raw Backscatter for 20220926



Wildfire Smoke...

Marysville CL-61 Raw Backscatter for 20221002

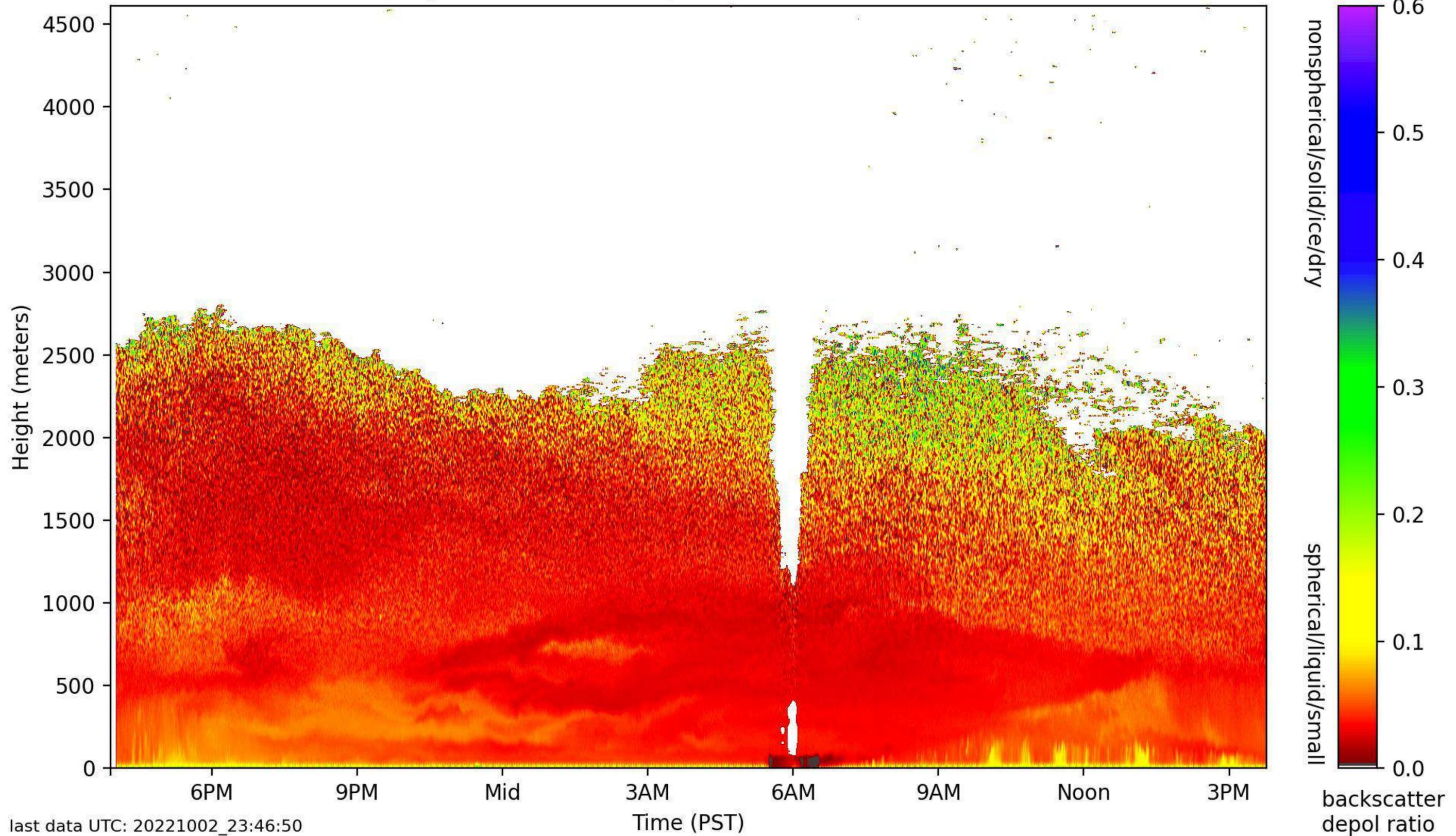
time generated:15:58:02



Wildfire Smoke...

Marysville CL-61 Depol Ratio for 20221002

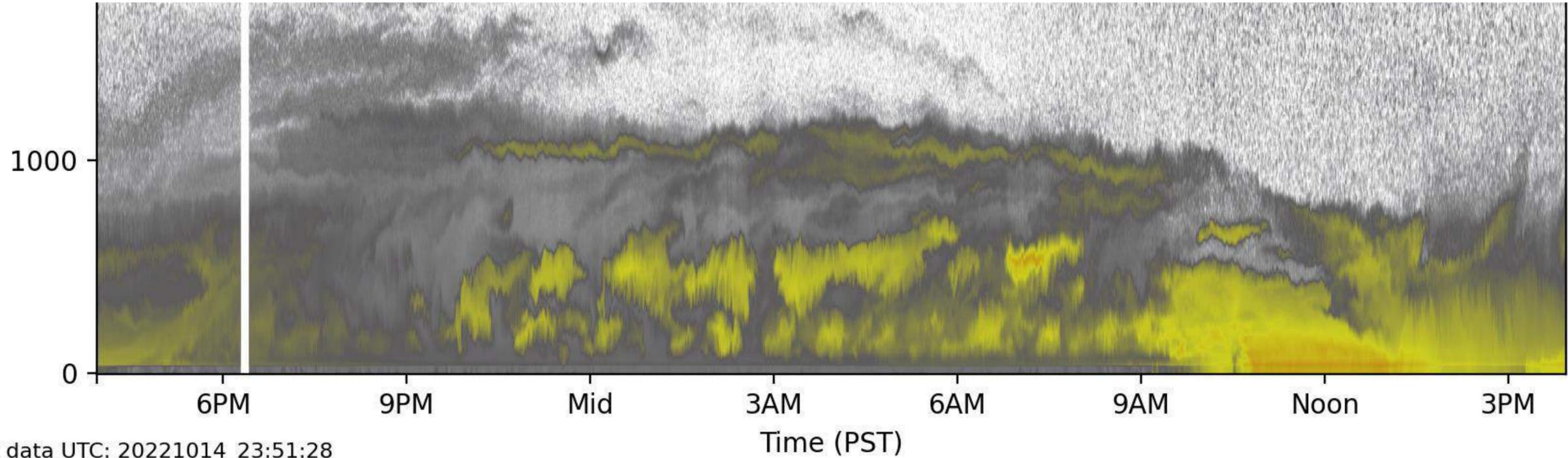
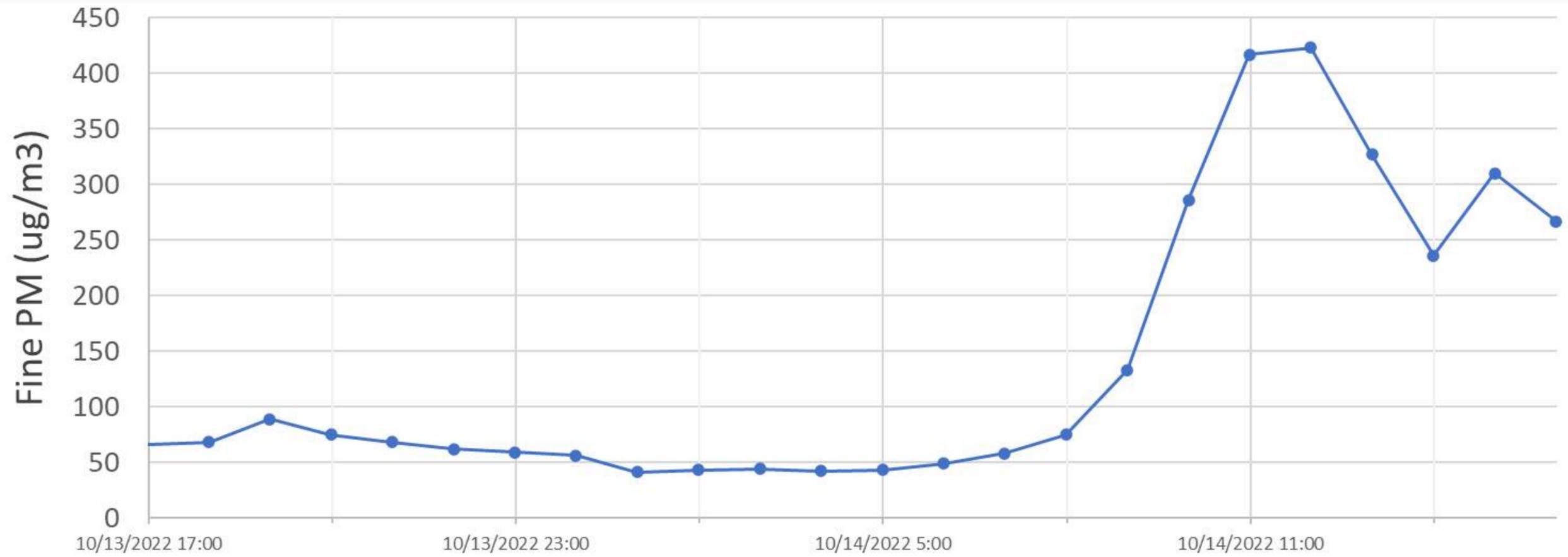
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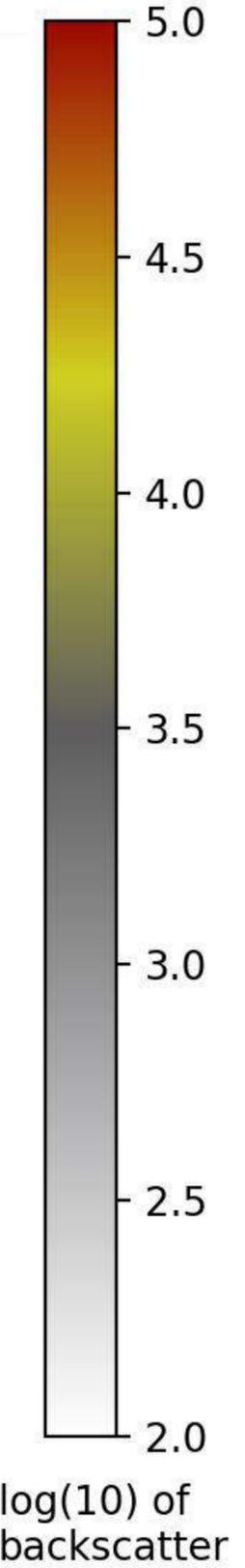
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time generated:15:56:01

Darrington Ceilometer Raw Backscatter for 20221014

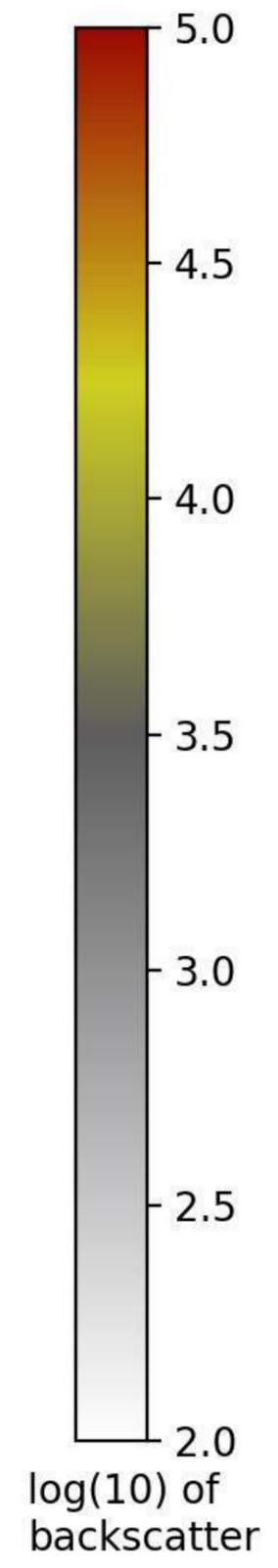
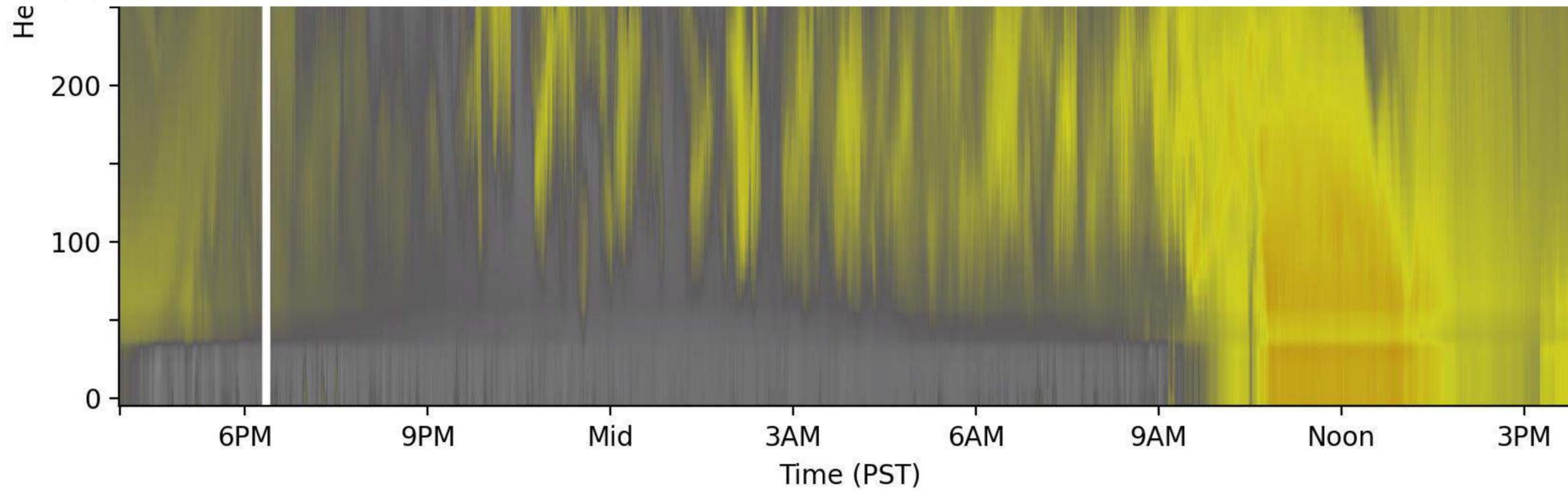
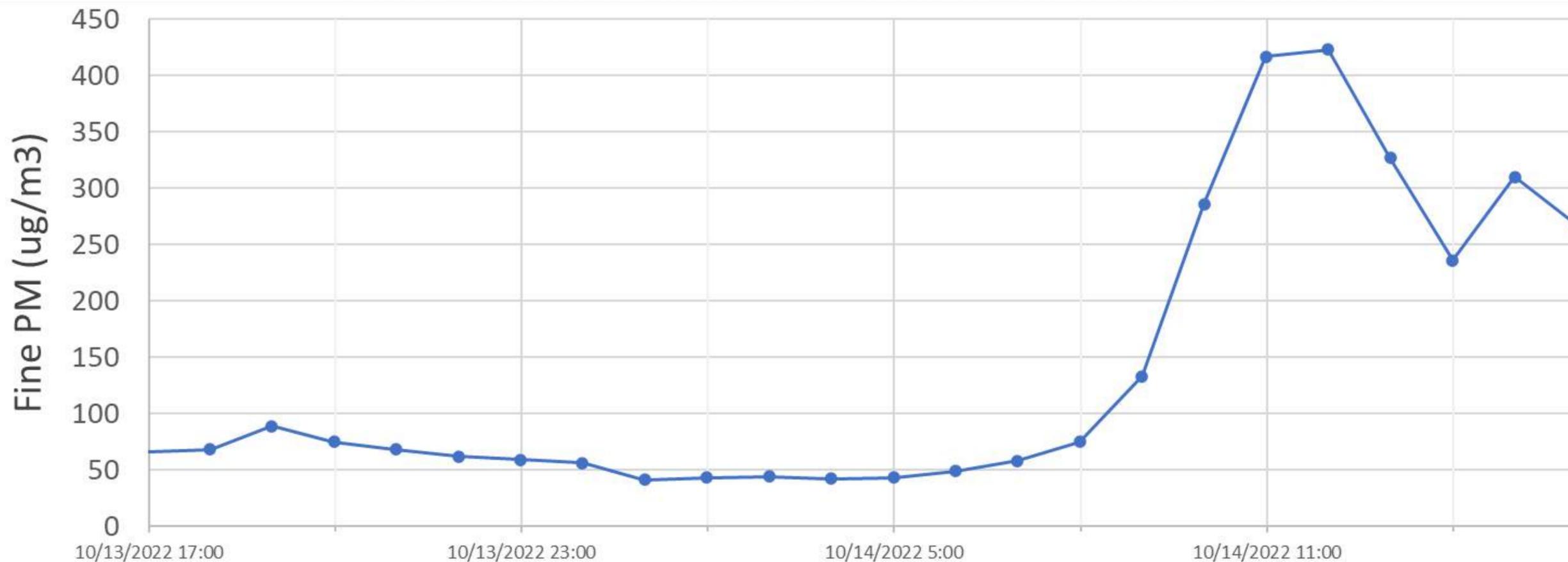


last data UTC: 20221014_23:51:28



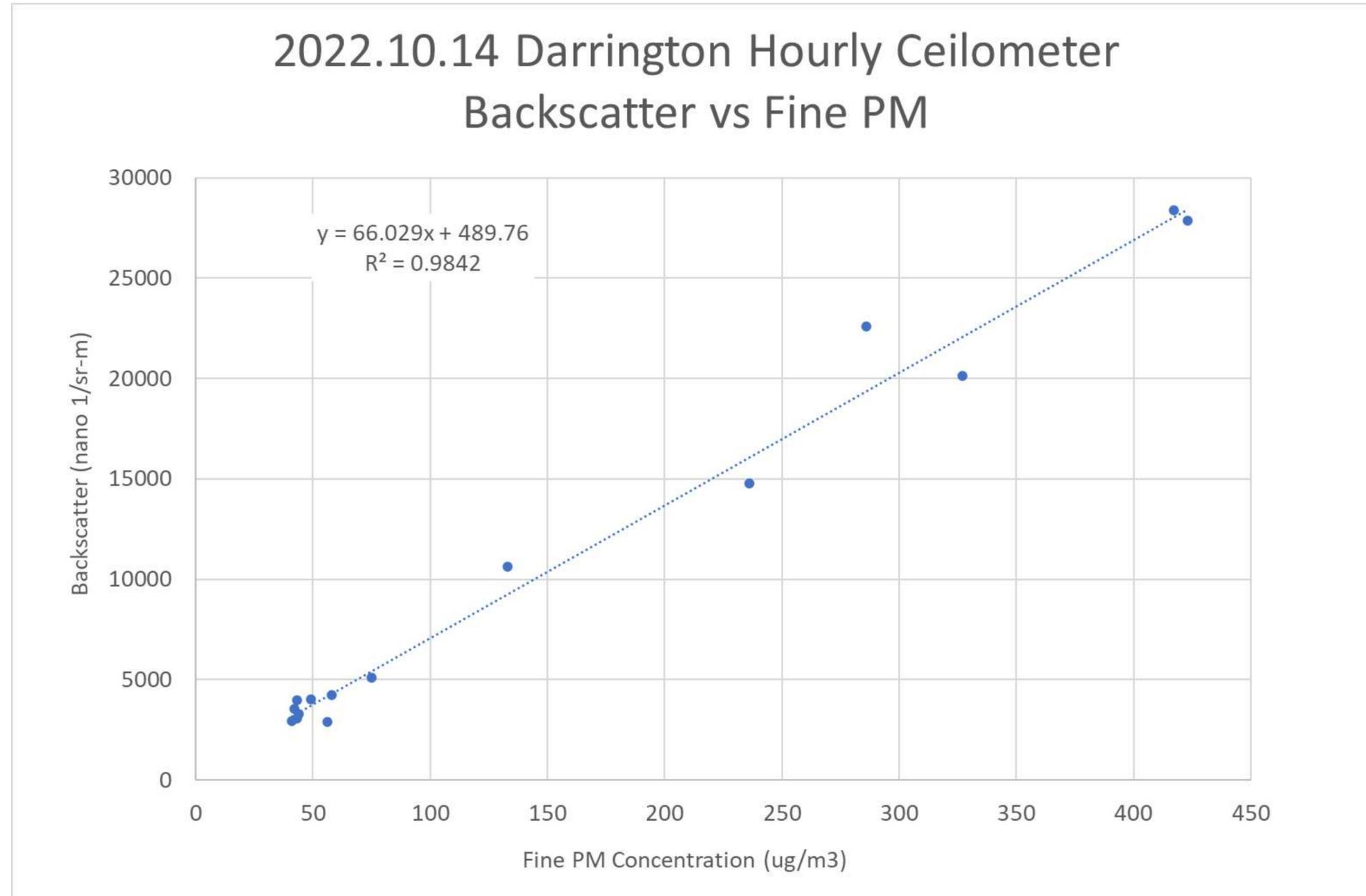
time generated:15:56:01

Lowest Heights - Smoothed Backscatter Profile 20221014



2022 Oct Wildfire Smoke Event Near Darrington

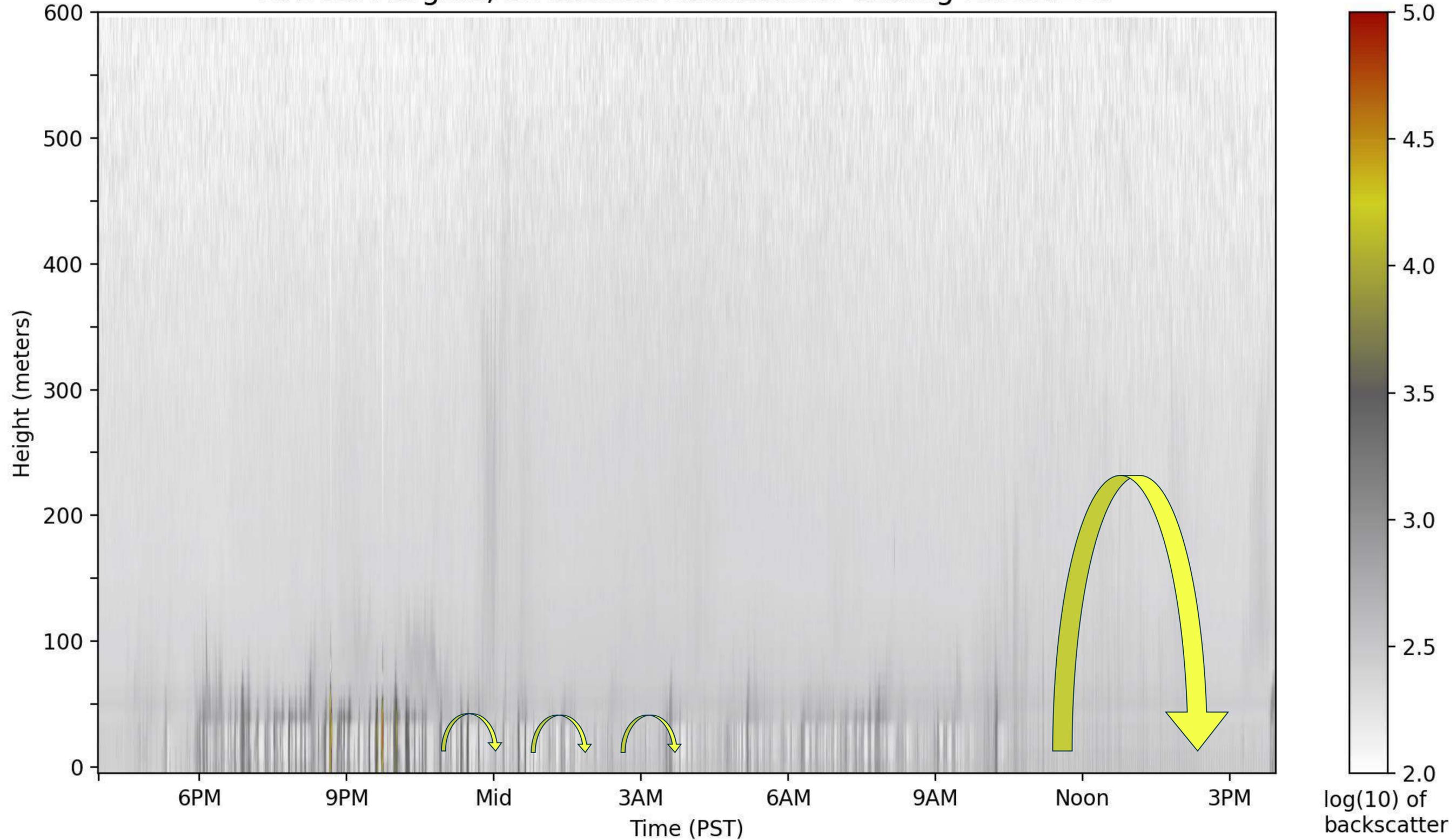
1. Oct 14, reached 420 ug/m³ on our BAM for hourly average (Agency record)
2. Bottom 6 height gates (up to 60m a.g.l.) showed excellent correlation ($r^2 > 0.95$) with the fine PM obs
3. All slopes were about 60:1 (nism:ug/m³)



Darrington with no cloud cover

time generated:15:56:02

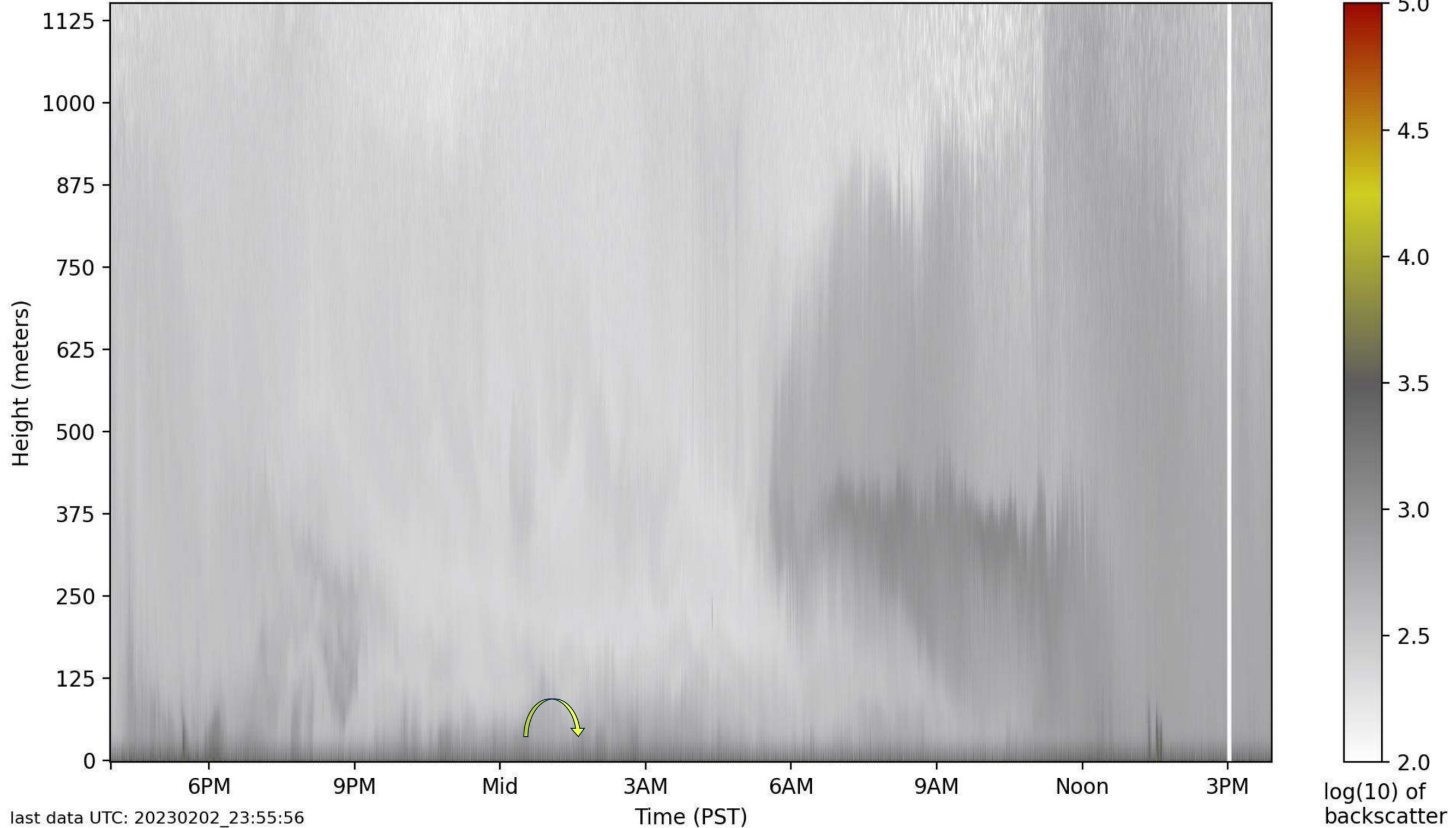
Lowest Heights, Smoothed Backscatter ending 20230129



Marysville with no cloud cover

time generated:15:58:02

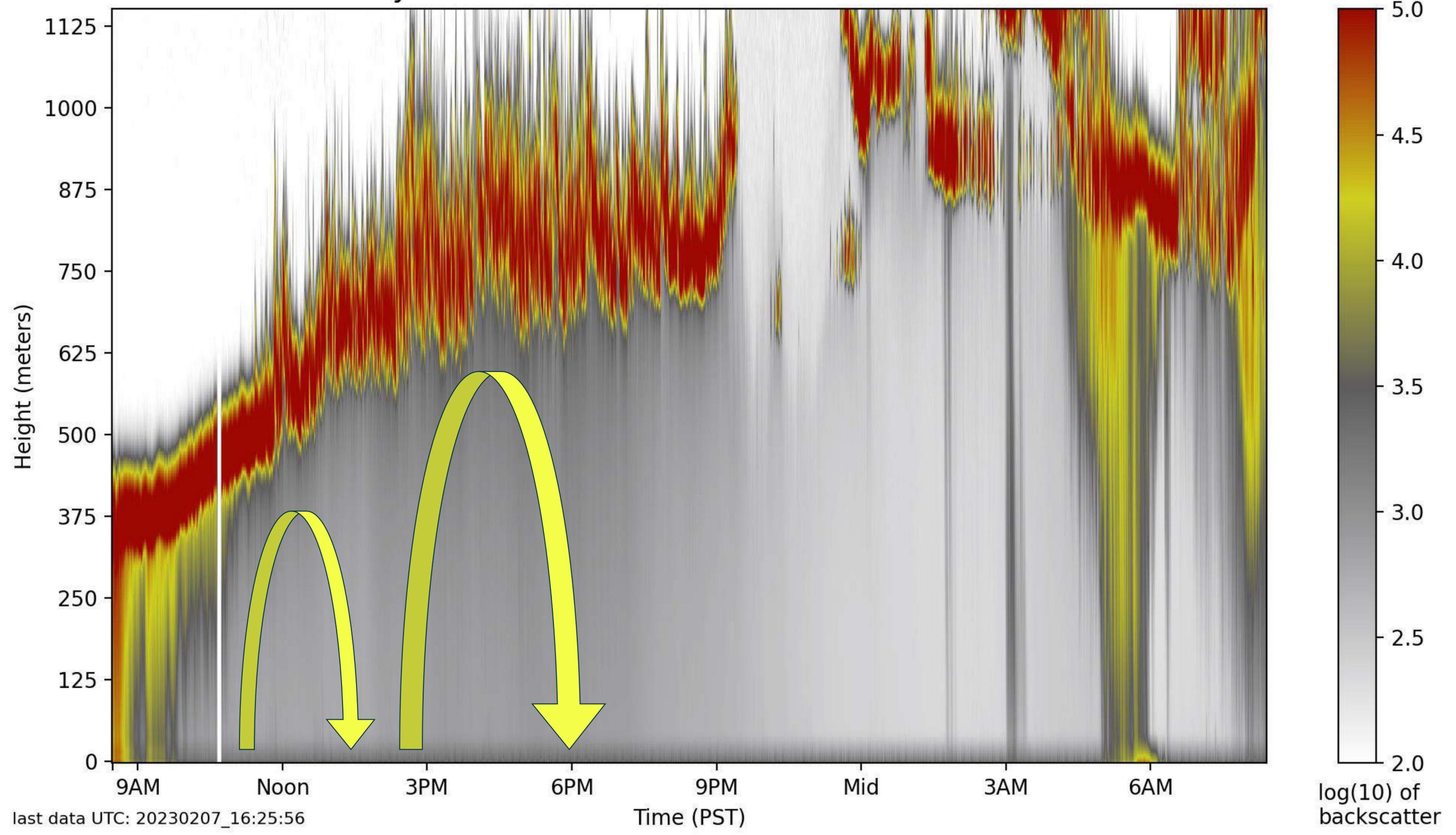
Marysville CL-61 Raw Backscatter for 20230202



Marysville, clouds prevent inversion event?

time generated:08:28:02

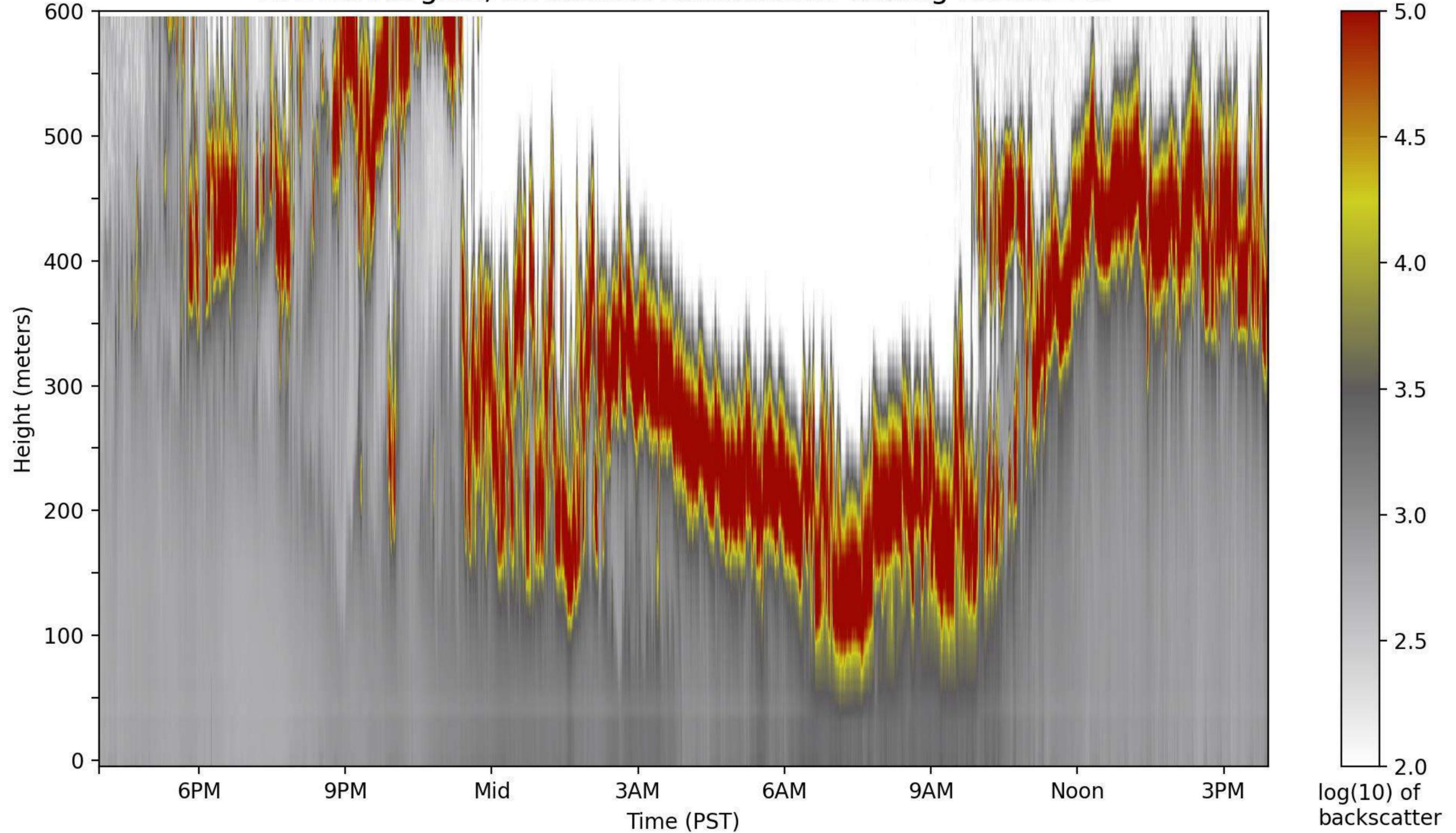
Marysville CL-61 Raw Backscatter for 20230207



Tacoma South L with stratus

time generated:15:57:02

Lowest Heights, Smoothed Backscatter ending 20230126



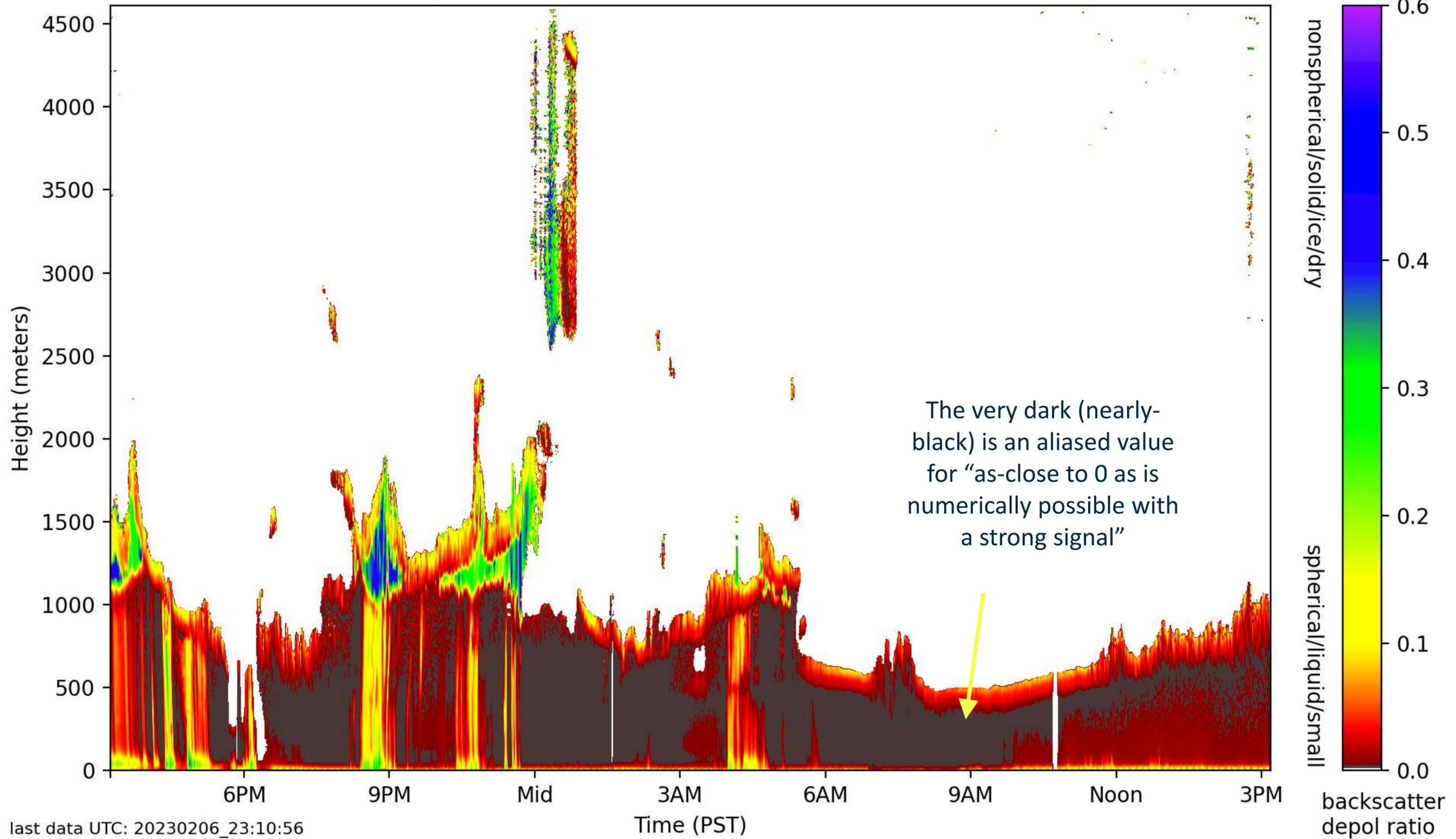
Thank You!
Questions, Comments??



Marysville stratus and rain

time generated:15:14:13

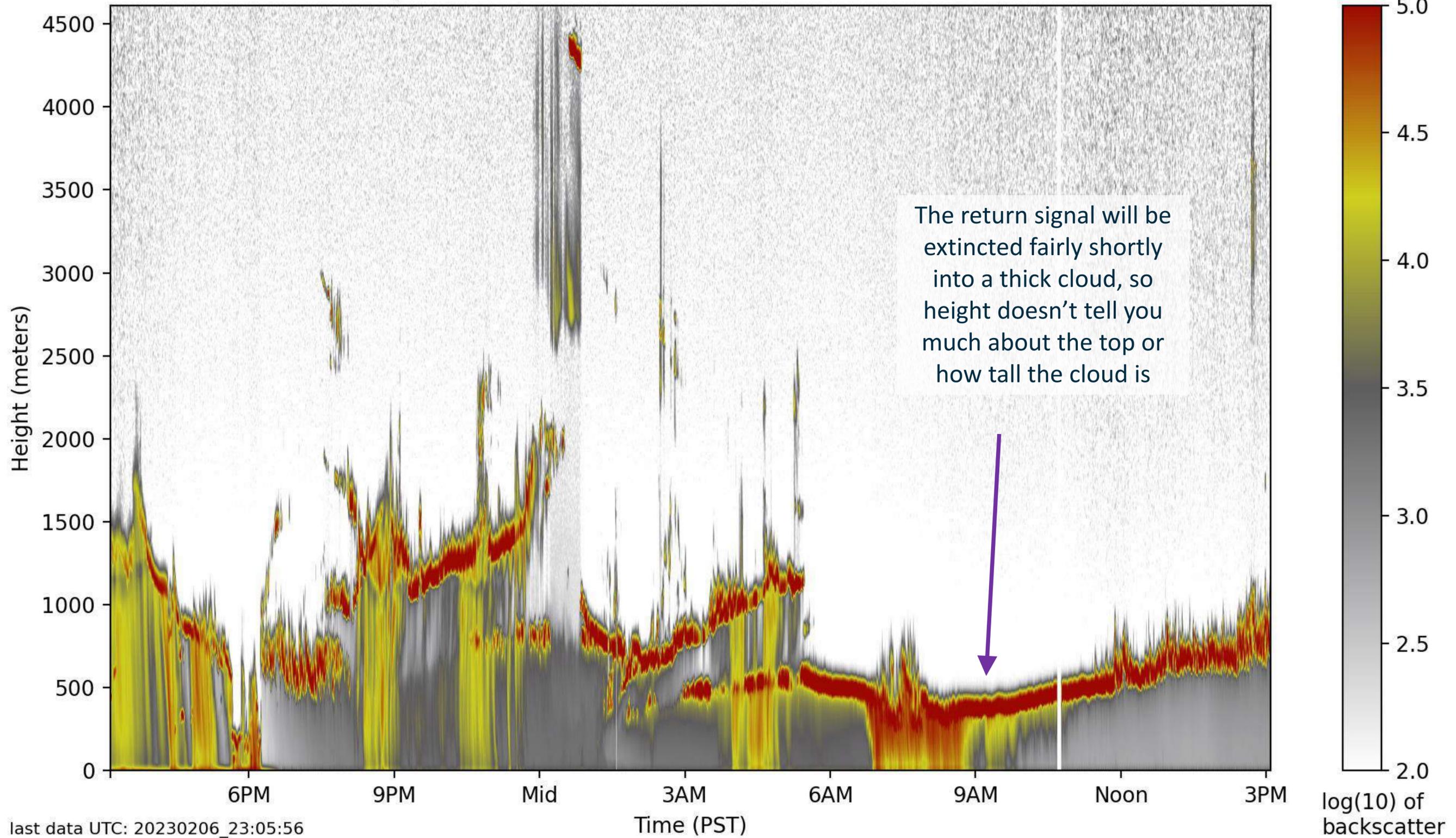
Marysville CL-61 Depol Ratio for 20230206



Marysville stratus and rain

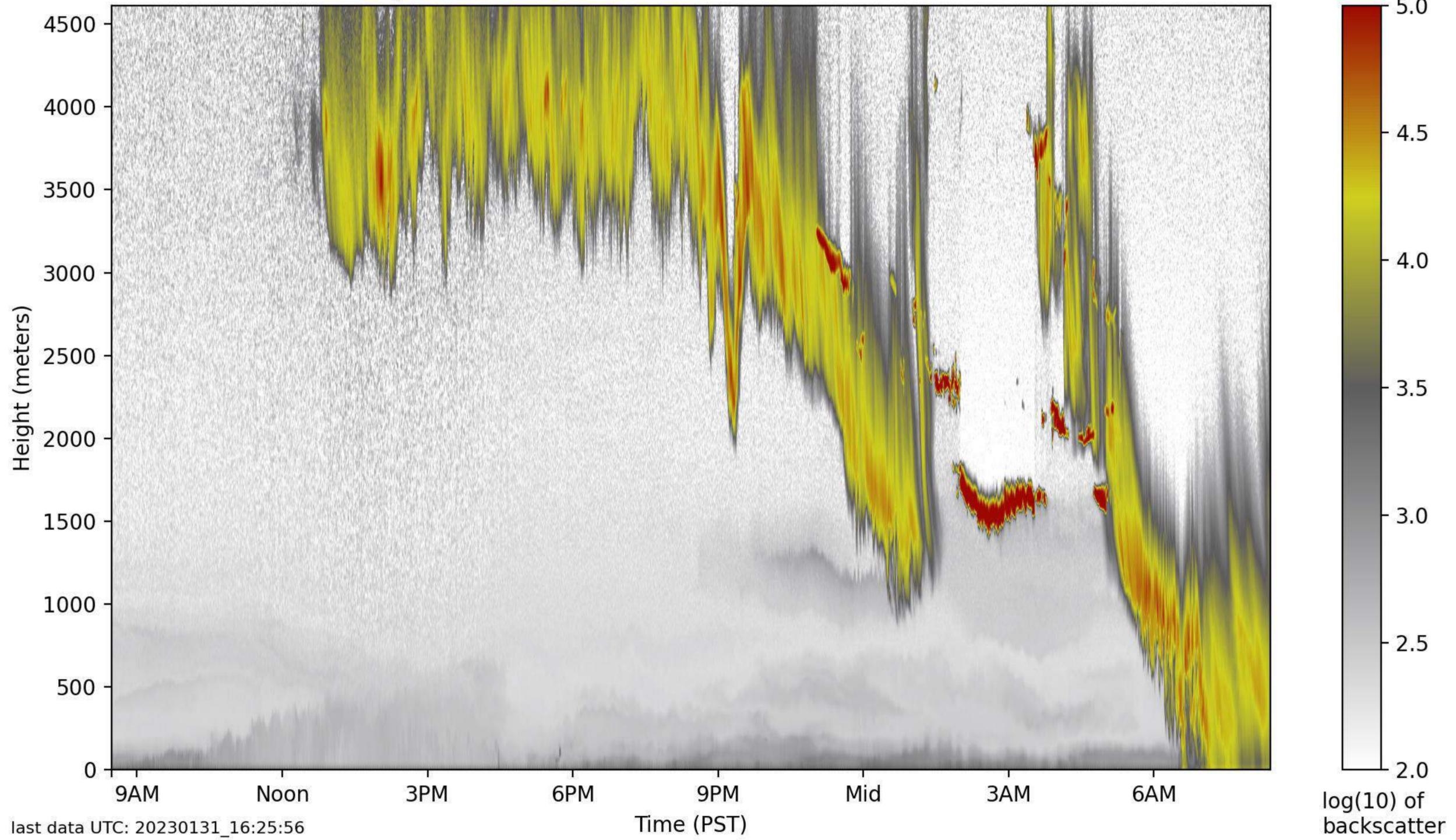
time generated:15:08:03

Marysville CL-61 Raw Backscatter for 20230206



time generated:08:28:02

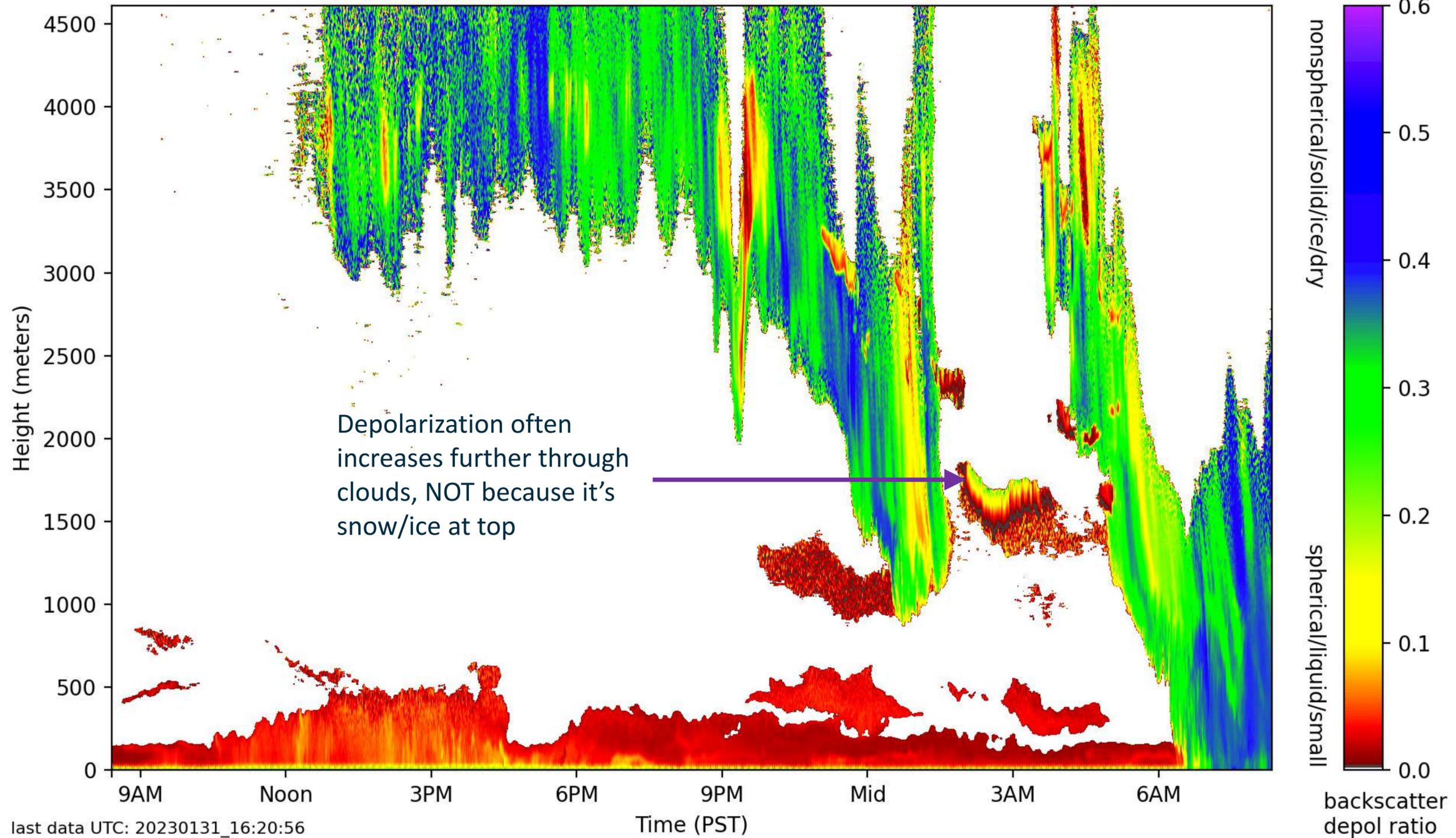
Marysville CL-61 Raw Backscatter for 20230131



last data UTC: 20230131_16:25:56

time generated:08:24:11

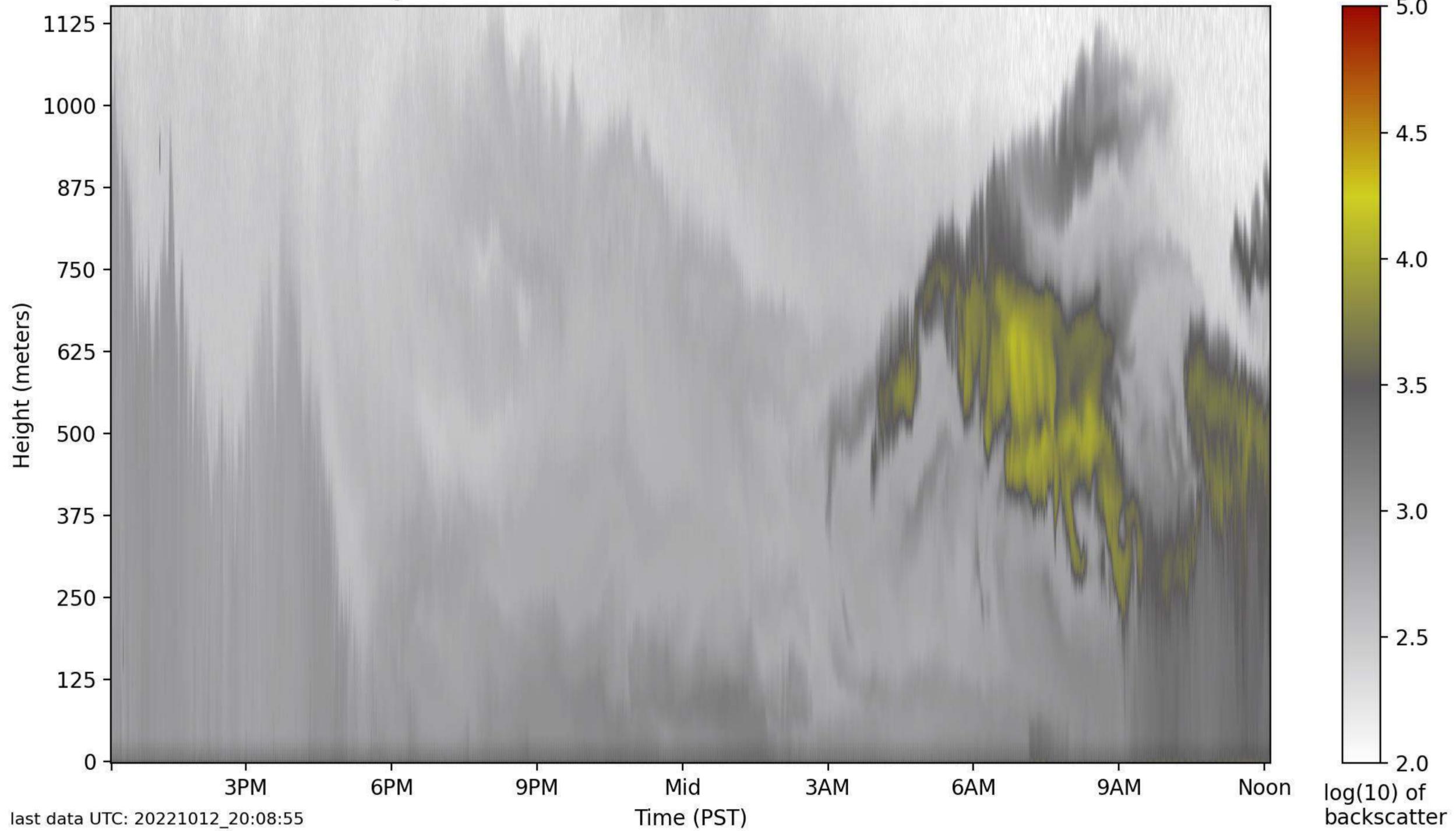
Marysville CL-61 Depol Ratio for 20230131



Wildfire Smoke...

time generated:12:13:02

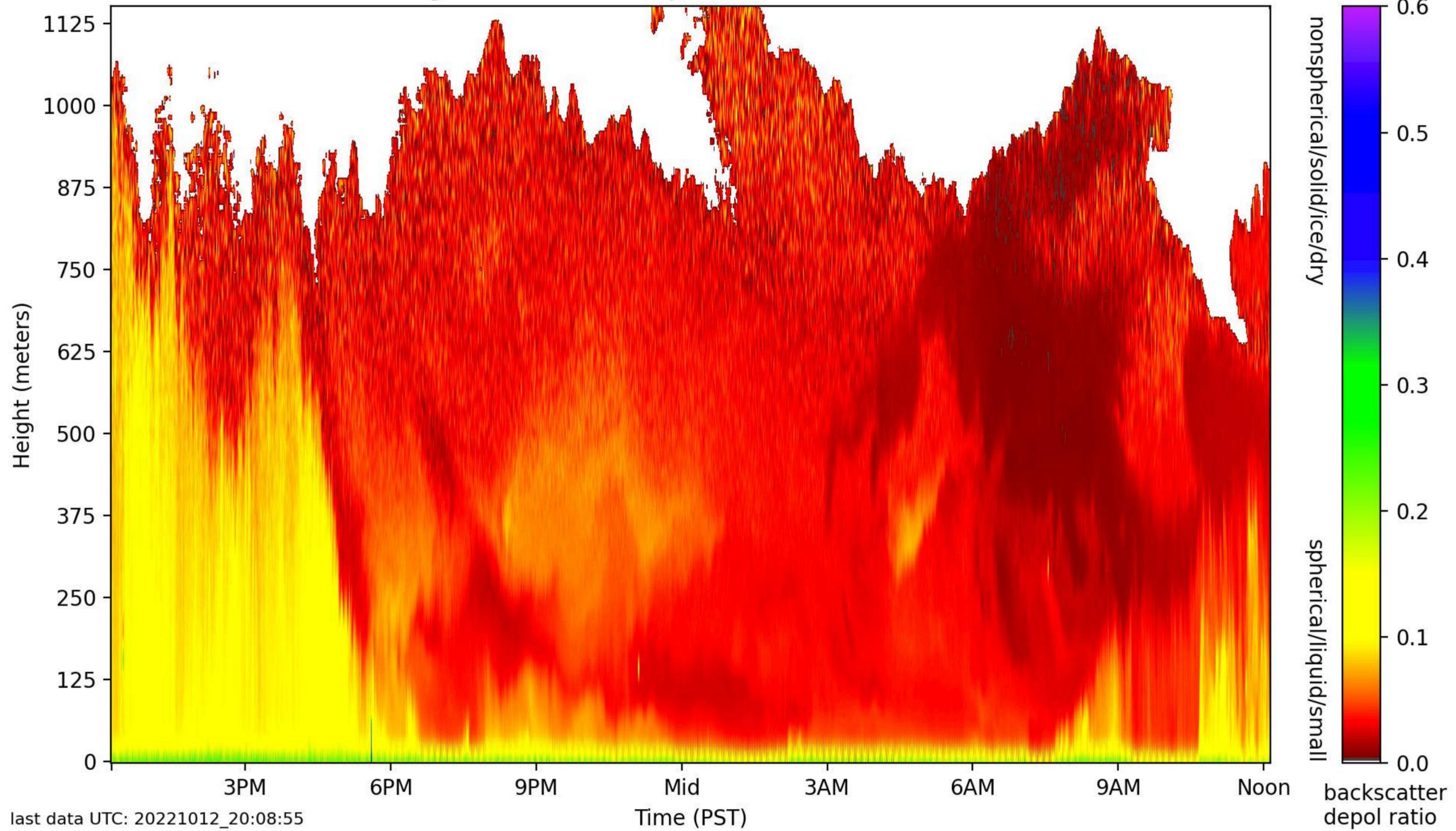
Marysville CL-61 Raw Backscatter for 20221012



Wildfire Smoke...

time generated:12:14:11

Marysville CL-61 Depol Ratio for 20221012



last data UTC: 20221012_20:08:55