Measuring non-tidal signals using gnssrefl

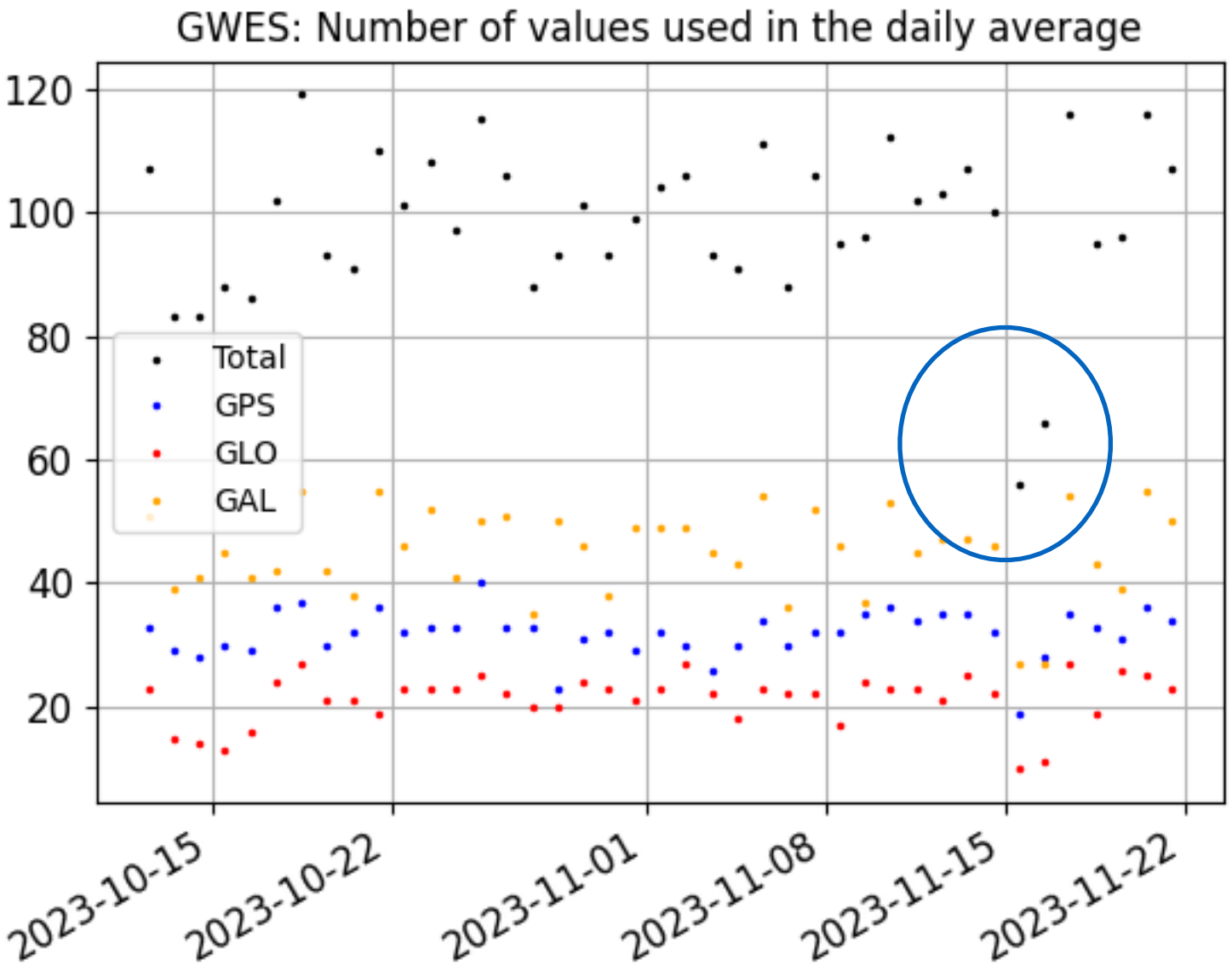
previously

- we picked an azimuth and elevation angle mask (also known as reflection zone)
- we checked the maximum resolvable RH.
- we translated a single RINEX file (15 sec)
- we checked the data to make sure our reflection mask was reasonably good.
- ran gnssir for a single file
- next steps:
  - create more SNR files (rinex2snr)
  - estimate H (gnssir)
- Today: turn this into water level with *daily_avg*

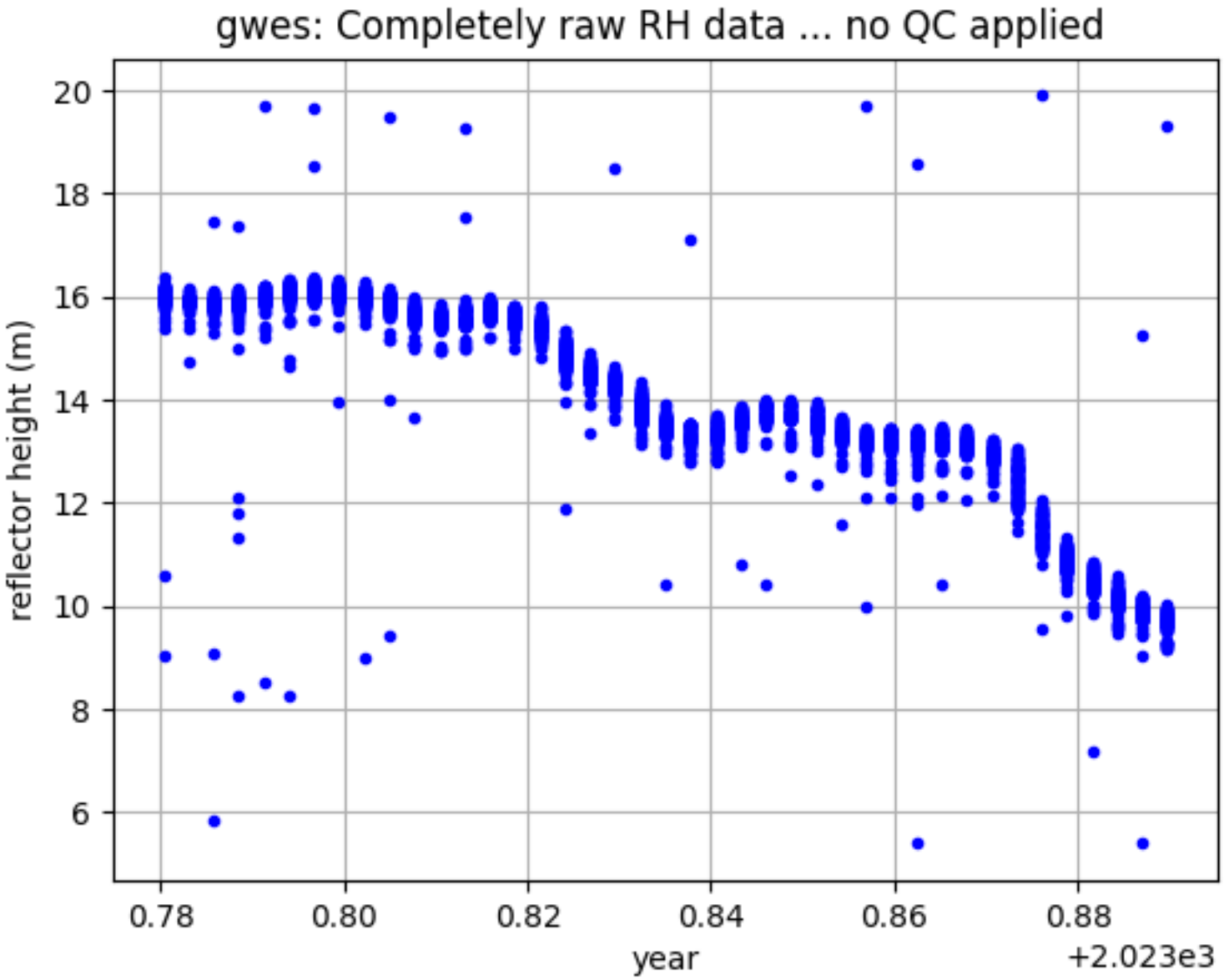
daily_avg

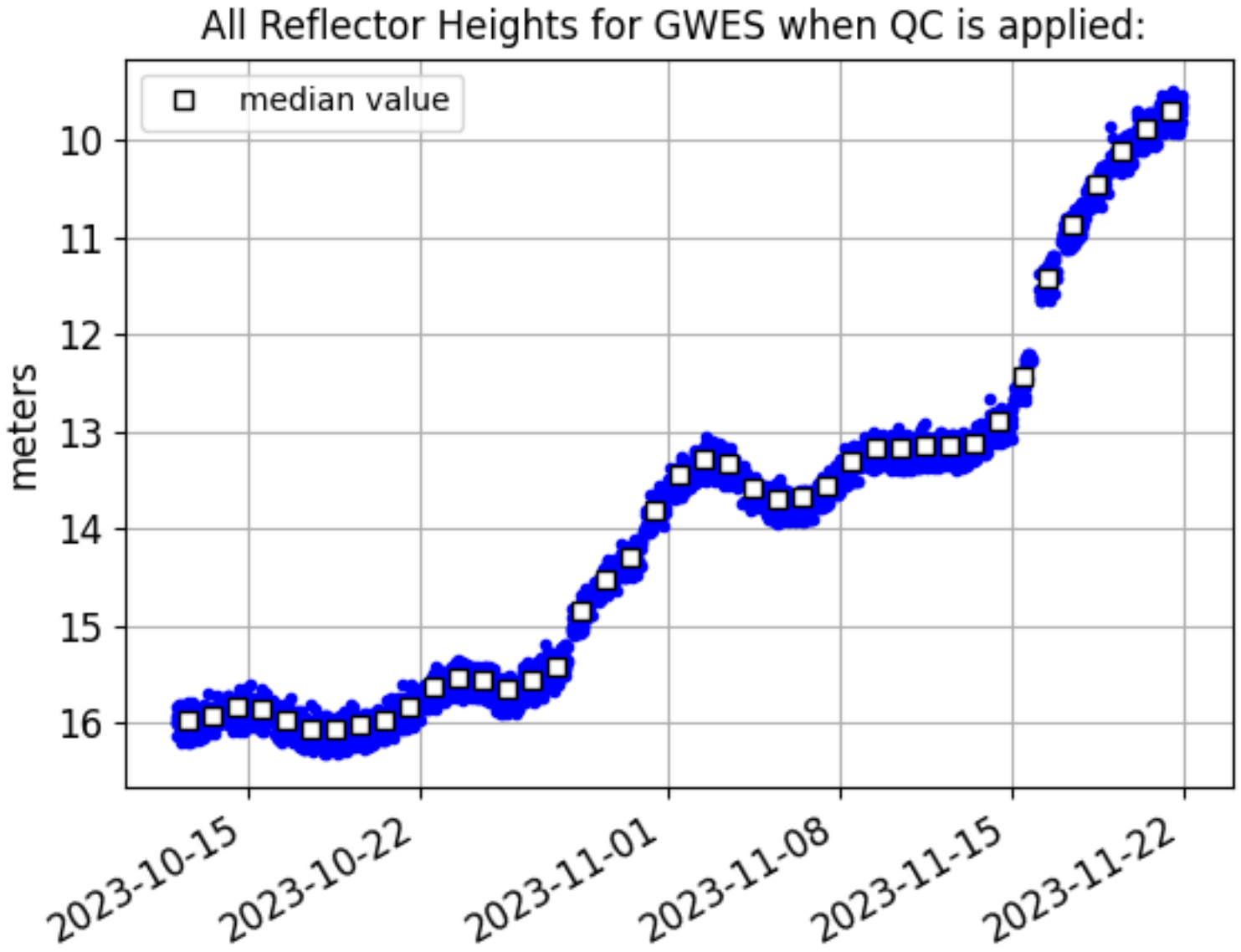
- *daily_avg* is what it sounds like
- Used for more than water - critical for snow, ice, and soil moisture products
- two required parameters (other than station name)
  - median filter value (meters)
  - number of required values per day
- Fine to start with non-optimal values and then iterate to what works best for your station
  - *daily_avg gwes 0.25 50*

Why more Galileo than GPS? Why so few Glonass ?

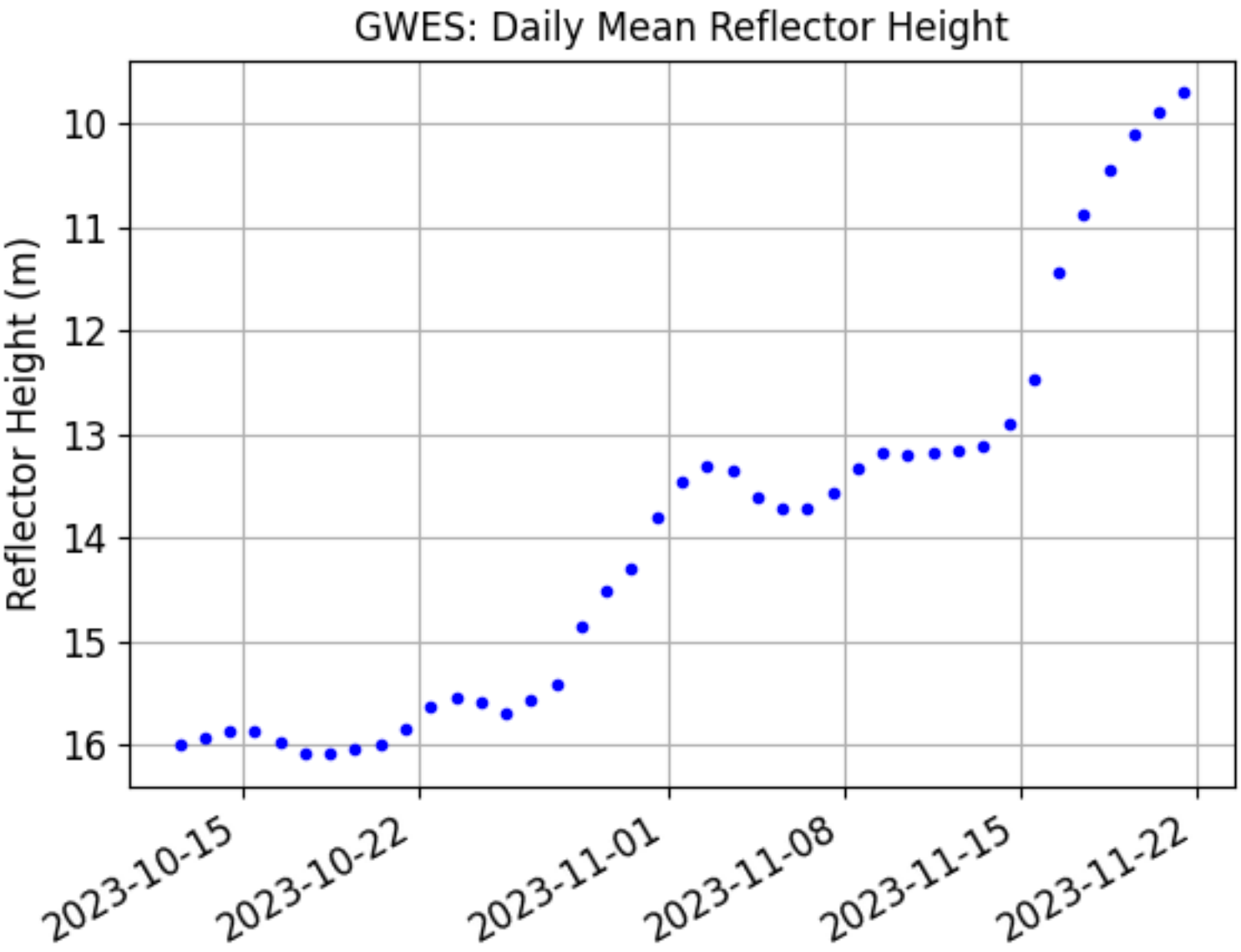


If you want, you can certainly try to improve your QC parameters …
usually all you have to do is increase your peak2noise ratio,
but for lakes and rivers, I don't usually bother.





Missing data?
Maybe 0.25 meters is too stringent since the river is rising quickly. We'll check that later.


GWES: Daily Mean Reflector Height
Reflector Height (m)
10
11
12
13
14
15
16
2023-10-15
2023-10-22
2023-11-01
2023-11-08
2023-11-15
2023-11-22

What about analyzing data from cheap sensors? Please see this use case for access to data from Wesel, Germany.

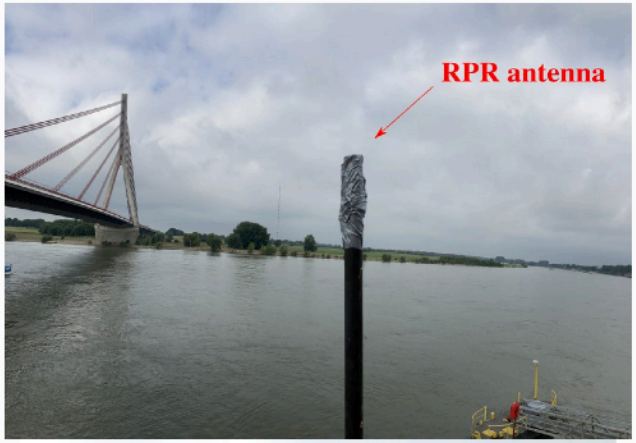
/ Rhine River, Wesel, Germany

Edit on GitHub

Rhine River, Wesel, Germany

The data collected here is from a Raspberry Pi Reflector. Detailed instructions for RPR setup are provided here.

This RPR is operating next to the Rhine in Wesel, Germany. We collected NMEA data from 23 March 2020 to 20 August 2021 using upright-pointing antenna and since then with sideways-looking antenna facing the river (tilting the antenna 90° from the vertical direction toward the river). In this example we also show impact of antenna set-up orientation.



For more information using a cheap sensors

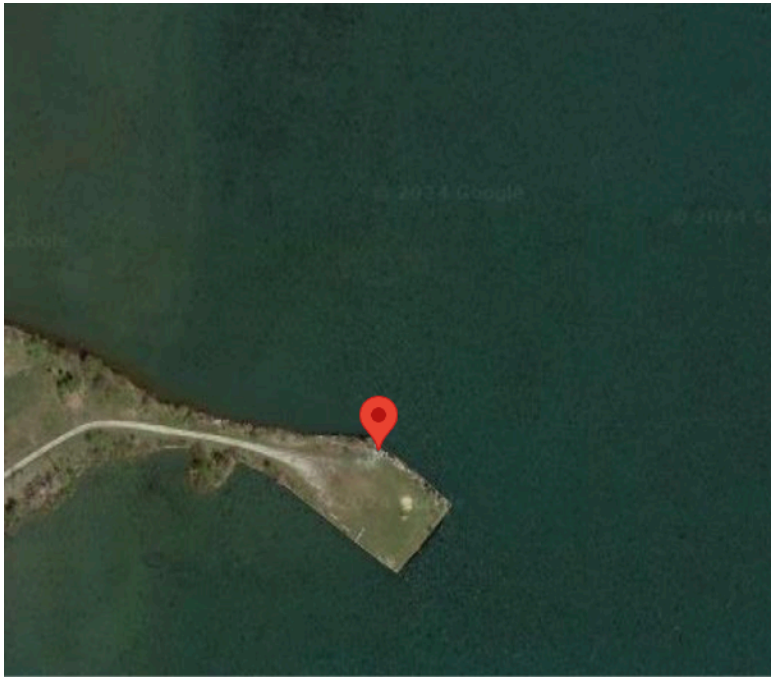
gnssrefl

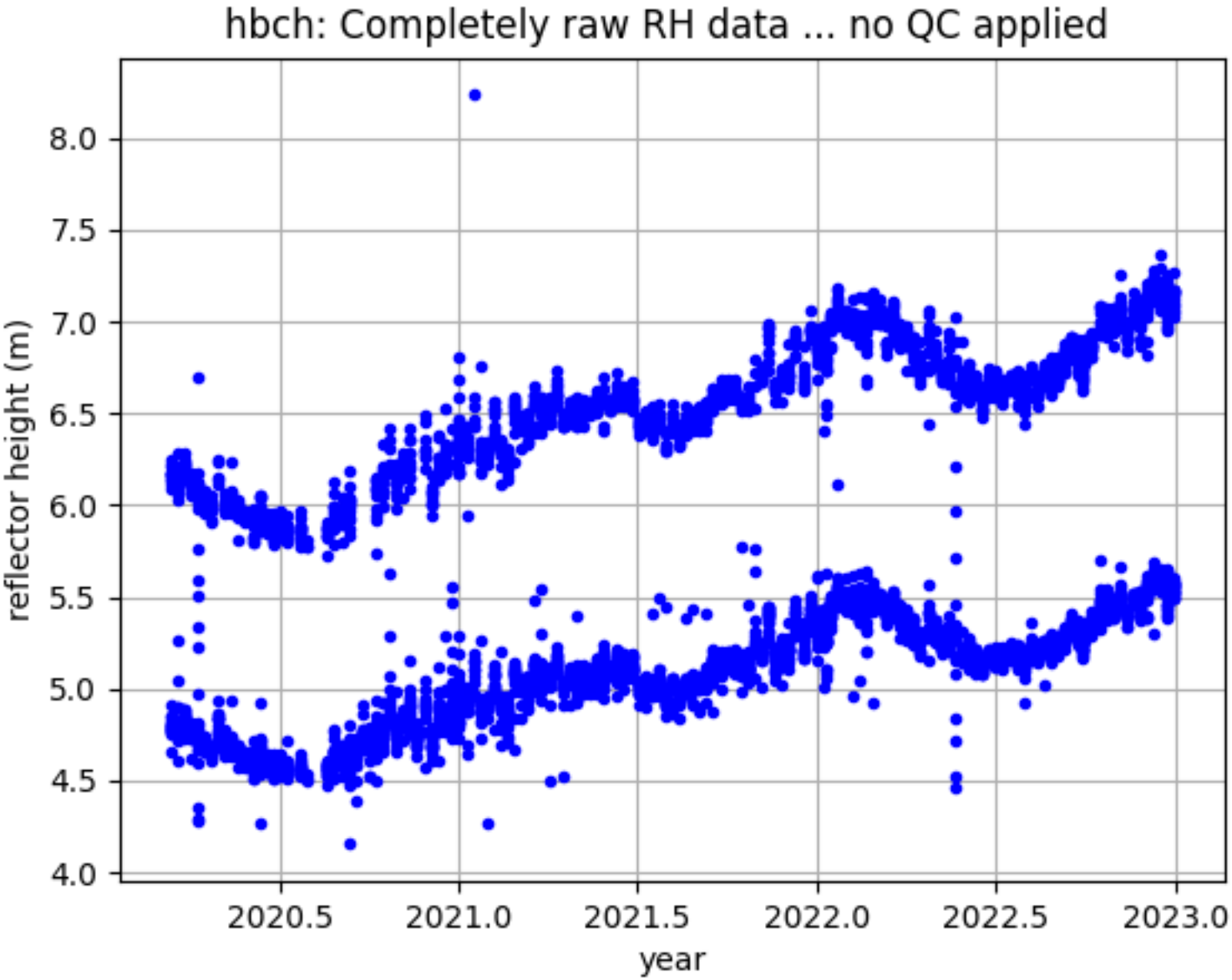
- Data are stored in NMEA format.
- The *nmea2snr* code requires you provide an a priori lat, lon, height on the command line. Or it will use a position from a previously created *gnssir_input*. I prefer the latter so I don't have to input Lat Lon Height every single time.
- This data set is GPS L1 only
- You should set azimuth and elevation angles from reflection zone tools and/or looking at SNR data.
- *gnssir_input WESL -lat 51.646 -lon 6.6067 -ht 73.057 -L1 T*
- I strongly encourage you to decimate where sensible, i.e.
- *nmea2snr WESL 2022 12 -dec 5*

One of the use cases (and the one I asked you to look at before the class) is on Lake Superior in Canada.

I looked for new lake sites to show you but was not able to find anything too exciting.

What really caught my eye is the following example.



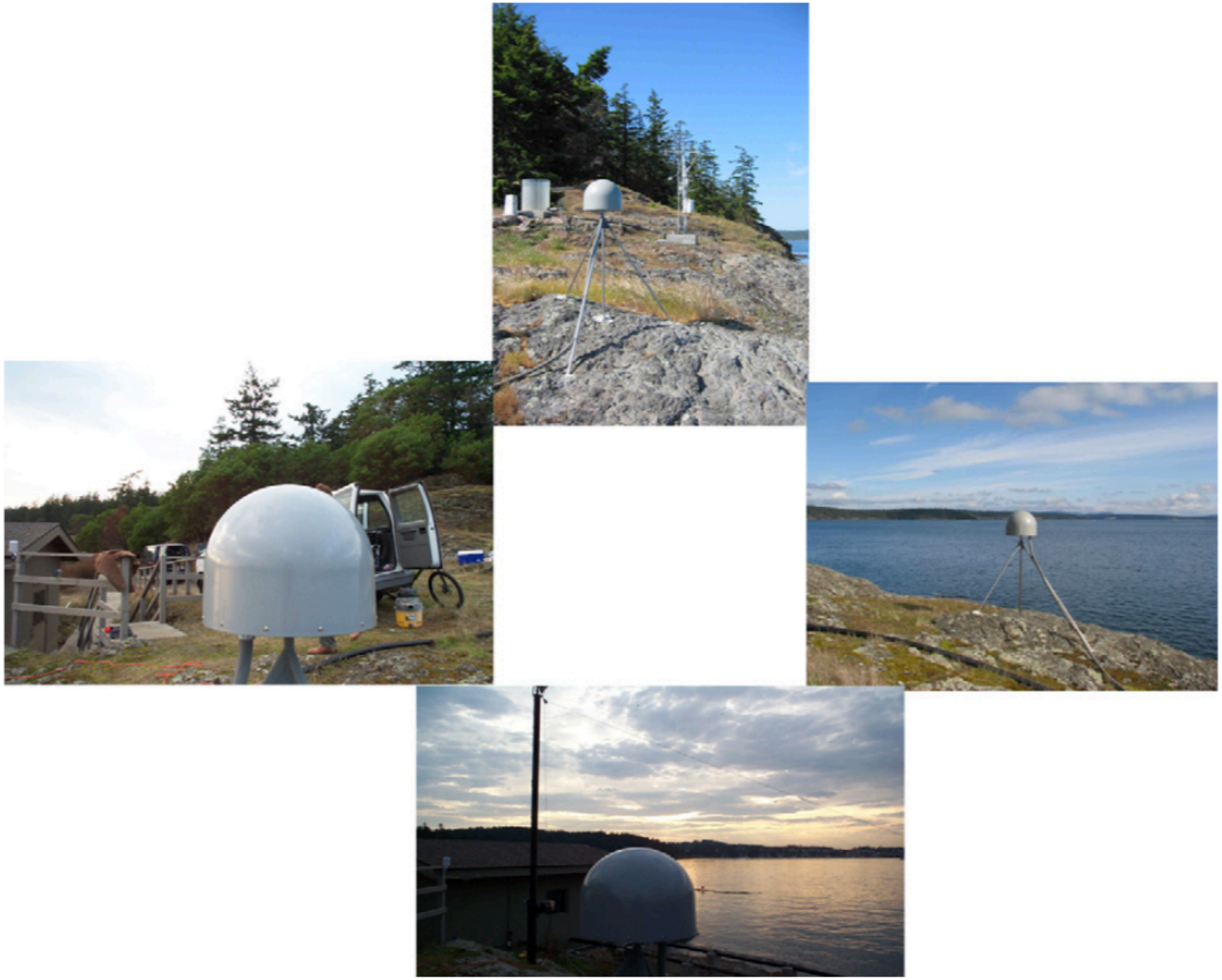


This unfortunately affects A LOT of sites that are archived by the NGS >>>> software bug. To me it looks like they are putting the L1 SNR data into both the L1 column and the L2 column.

Measuring tidal signals using gnssrefl

- Picking a good site mask
- Check sampling rate
- RH dot correction
- Inter-frequency biases
- Surface effects
- Length of arcs

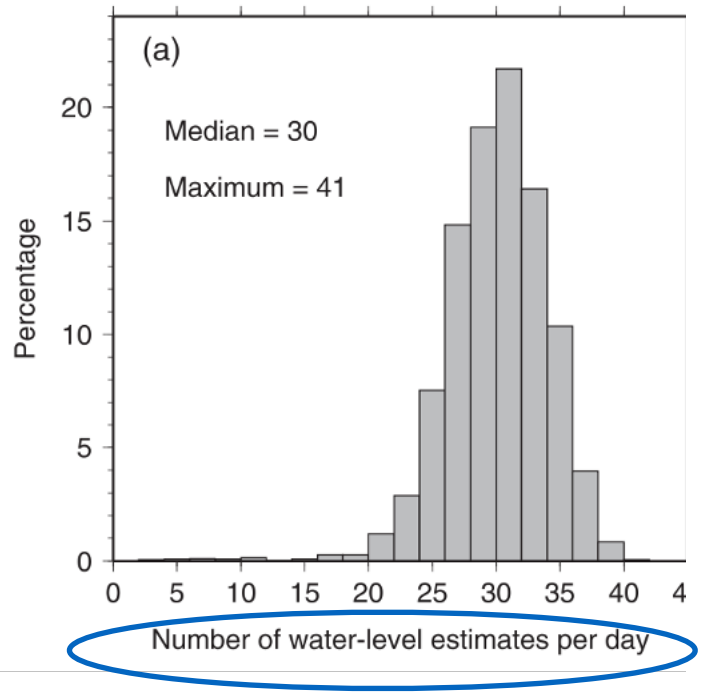
Start with sc02, Friday Harbor, Washington



A 10-Year Comparison of Water Levels Measured with a Geodetic GPS Receiver versus a Conventional Tide Gauge

TABLE 1. Estimated amplitudes A and phase lags G of selected tidal constituents, based on data collected during 2006–15.

	Acoustic gauge		GPS		
Tide	A (cm)	G (°)	A (cm)	G (°)	Diff (cm)
Sa	6.1	274.8	5.8	277.6	0.37
Ssa	1.5	227.7	1.6	220.1	0.21
Mf	2.0	168.2	2.0	162.4	0.20
Q_1	7.4	250.0	7.5	249.9	0.13
O_1	43.4	258.1	44.0	258.6	0.78
P_1	23.6	278.7	23.1	278.0	0.54
S_1	2.6	31.2	1.6	59.2	1.37
K_1	76.0	280.0	76.0	279.0	1.33
J_1	4.0	311.6	4.0	310.5	0.08
N_2	12.1	342.4	12.0	343.1	0.15
M_2	56.0	10.5	56.4	10.2	0.50
S_2	13.3	36.0	13.2	34.9	0.25
MK_3	1.2	26.8	1.2	33.9	0.16
M_4	1.7	121.2	1.5	121.1	0.17
MS_4	1.0	131.4	0.8	131.4	0.17
M_6	0.5	236.0	0.4	255.1	0.18



Now that Friday Harbor is operating a modern receiver, what do the data look like?

Remember - setting a good reflection mask is key

- Defaults in quickLook are generally not going to work for tides. Use the reflection zone tool.
- Find out the appropriate RH to use (or use sea level)
- Is the sample rate sufficient to estimate that RH?
  - Like almost every PBO site, it is 15 seconds, which is far superior to the generic geodetic rate of 30 seconds.
  - From experience, I know the answer is yes, but you should always check until you have that experience.

GNSS-IR Reflection Zone Mapping

Station Location

Input 4 character station name: sc02 (uses Nevada Reno database)

OR

Input coordinates: Lat. (deg) 0.0 Lon. (deg) 0.0 EllipseHt (m) 0.0

Reflection Height (meters)

(•) Use Mean Sea Level ( ) Set Reflector Ht. Value 2

Frequency

(•) L1 ( ) L2 ( ) L5

Compute Nyquist (this takes a few seconds)

(•) no ( ) yes 30 rcvr sample rate (sec)

Elevation Angles (degrees)

(•) 5,10,15 ( ) 5,10,15,20,25 ( ) 5,7,10,12 ( ) 5,6,7 ( ) 10,15,20 ( ) 5,7,10

Azimuth Angles (degrees)

If needed, you can cross North, e.g. -90 to 90

Start (deg) 0 End (deg) 360

Constellation

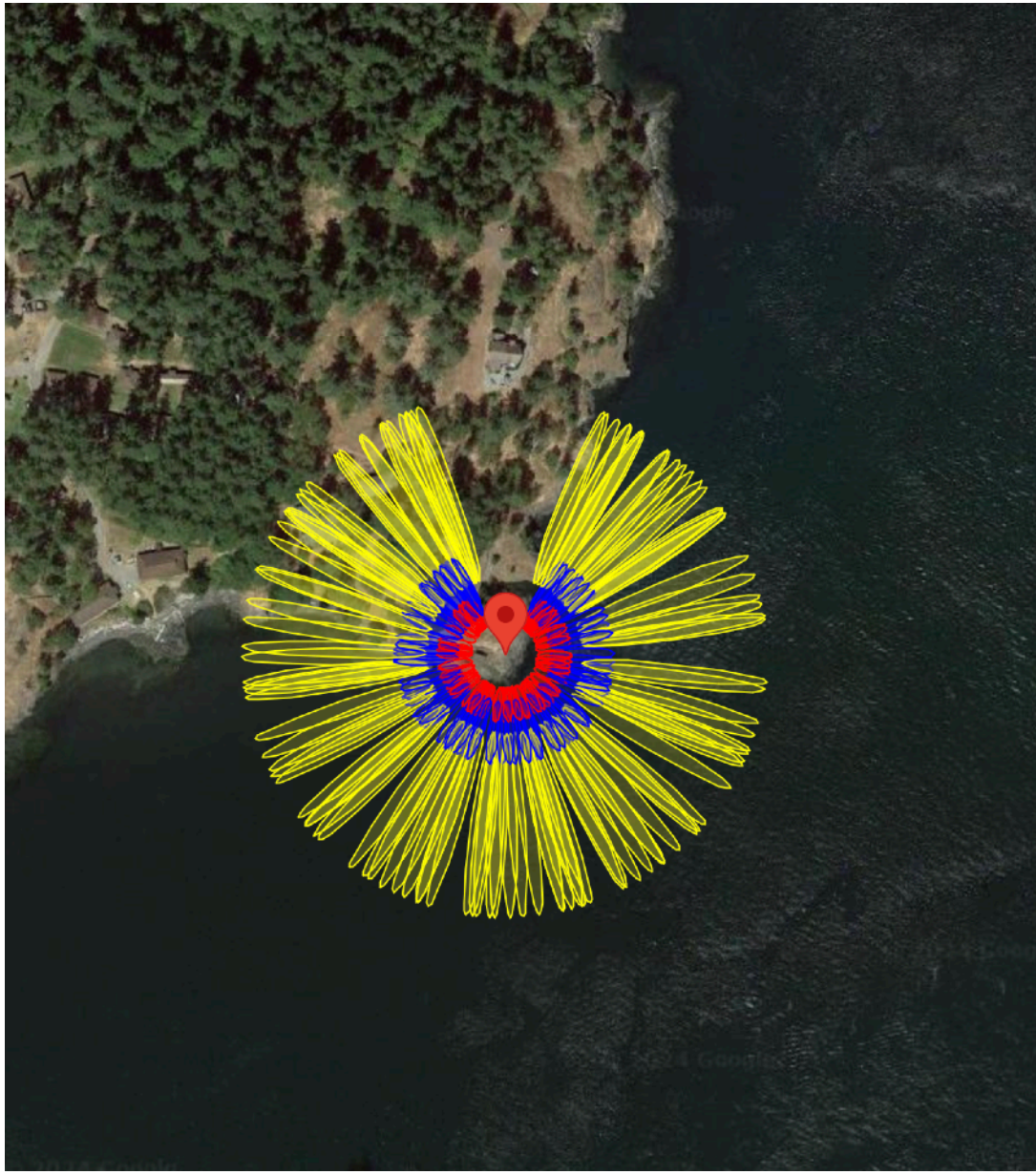
(•) GPS ( ) Galileo ( ) Glonass ( ) Beidou(MEO)

submit

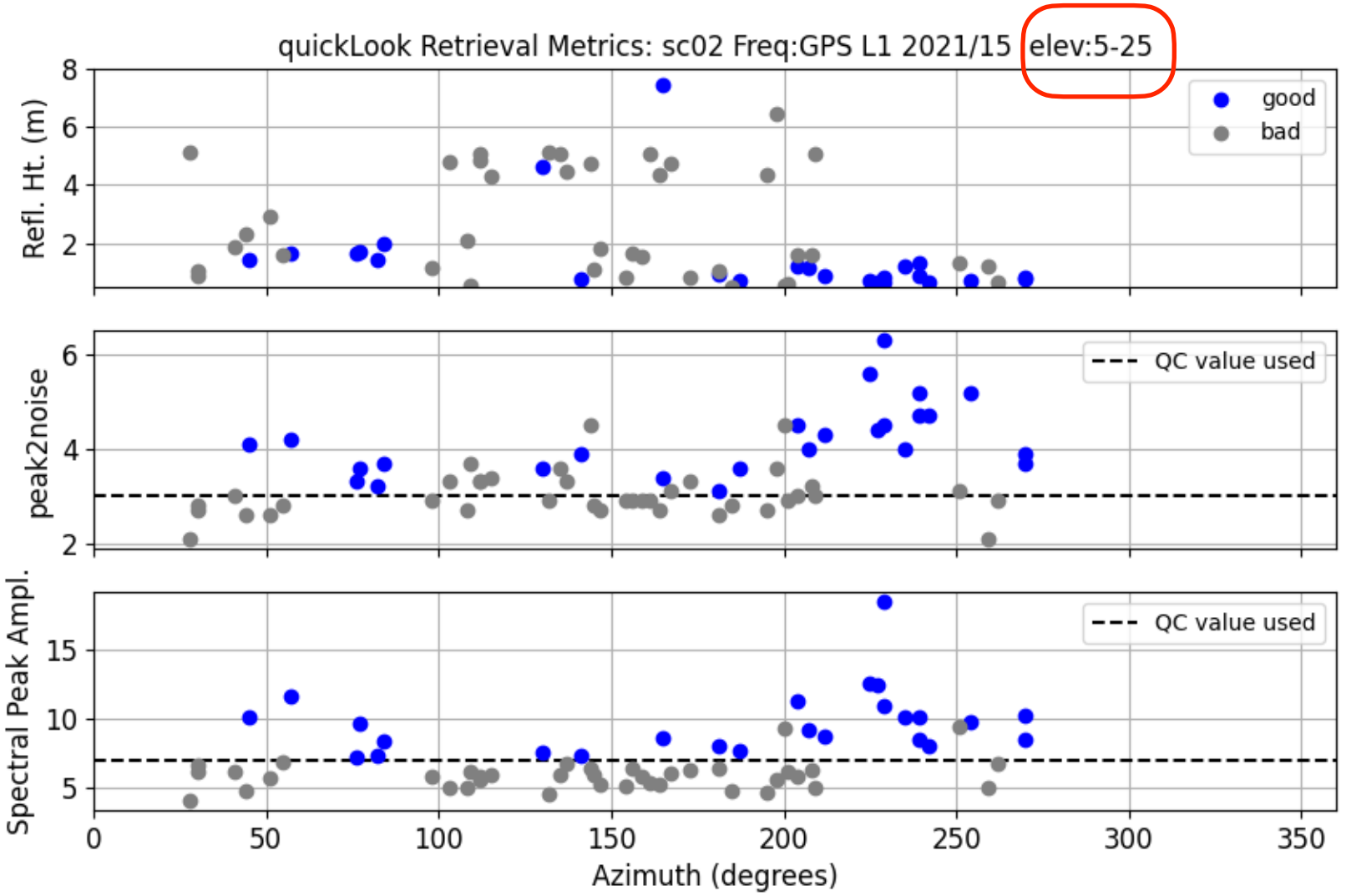
Defaults in the mapping tool are not necessarily the defaults in quickLook

We expect the RH signals to be ~5.8 meters (+- tides).

Station: sc02
Latitude: 48.54619475
Longitude: -123.00761051
Ellipsoidal Height(m): -15.049
Reflection Ht. (m): 5.801
Elevation Angles (deg) : 5,10,15
Azimuth Angles (deg) : 0 to 360
Constellation : GPS
Frequency: L1

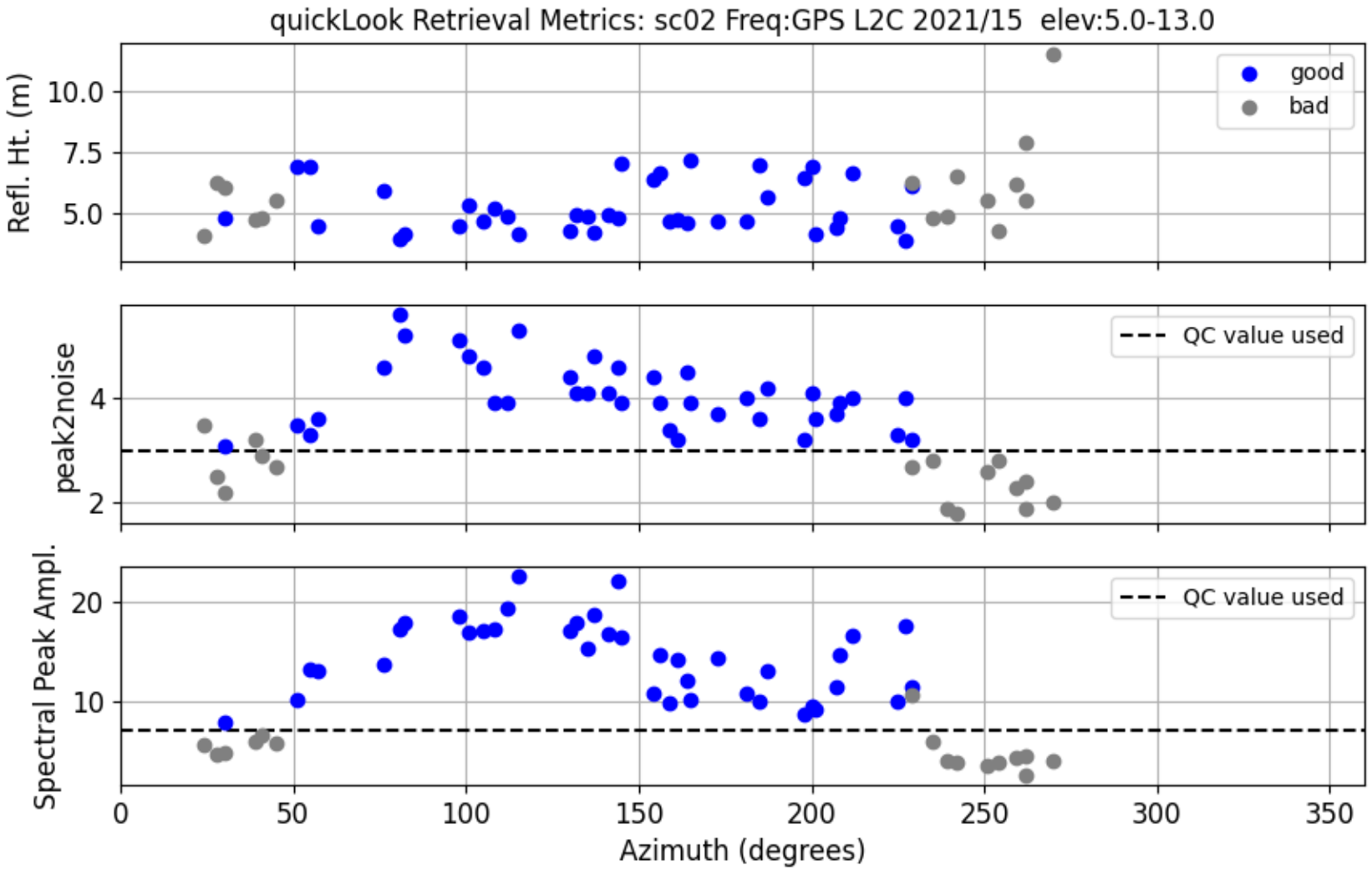


Using defaults, so includes soil/rock. All those good tracks at 0.5 meters are either the direct signal effect or maybe soil.



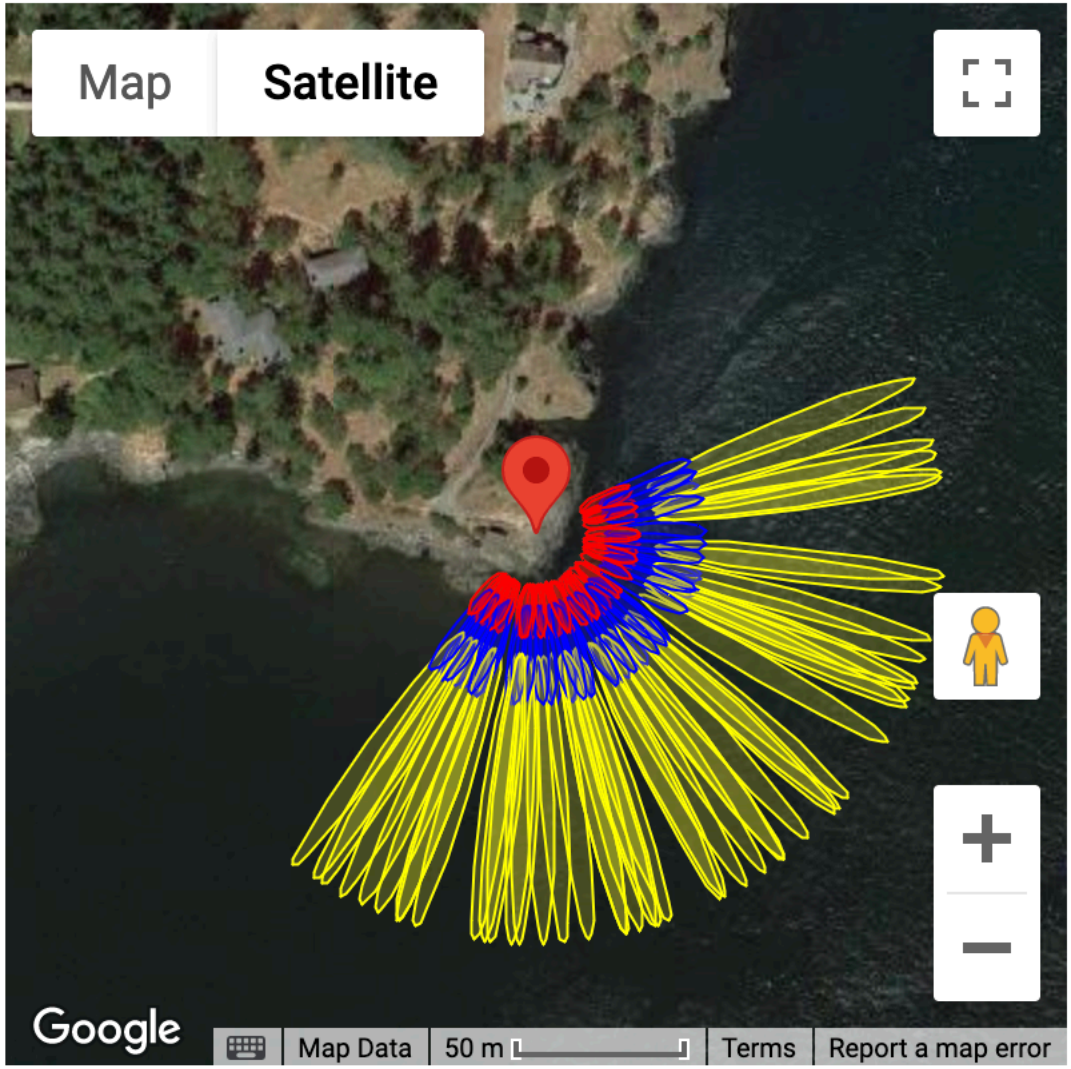
Better mask and better data: L2C

quickLook sc02 2021 15 -e1 5 -e2 13 -h1 3 -h2 12 -fr 20



the good retrievals generally line up with this reflection zone map

quickLook sc02 2021 15 -e1 5 -e2 13 -h1 3 -h2 12 -fr 20



Make more SNR files

```
rinex2snr sc02 2021 15 -doy_end 45 -orb gnss
```

Store your analysis strategy (I listed frequencies, but you could try setting allfreq as T)

```
gnssir_input sc02 -e1 5 -e2 13 -h1 3 -h2 12 -peak2noise 3.0 -frlist 1 20 5 101 102 201 205 206 207 -azlist2 60 220 -delTmax 40
```

Estimate RH from the data

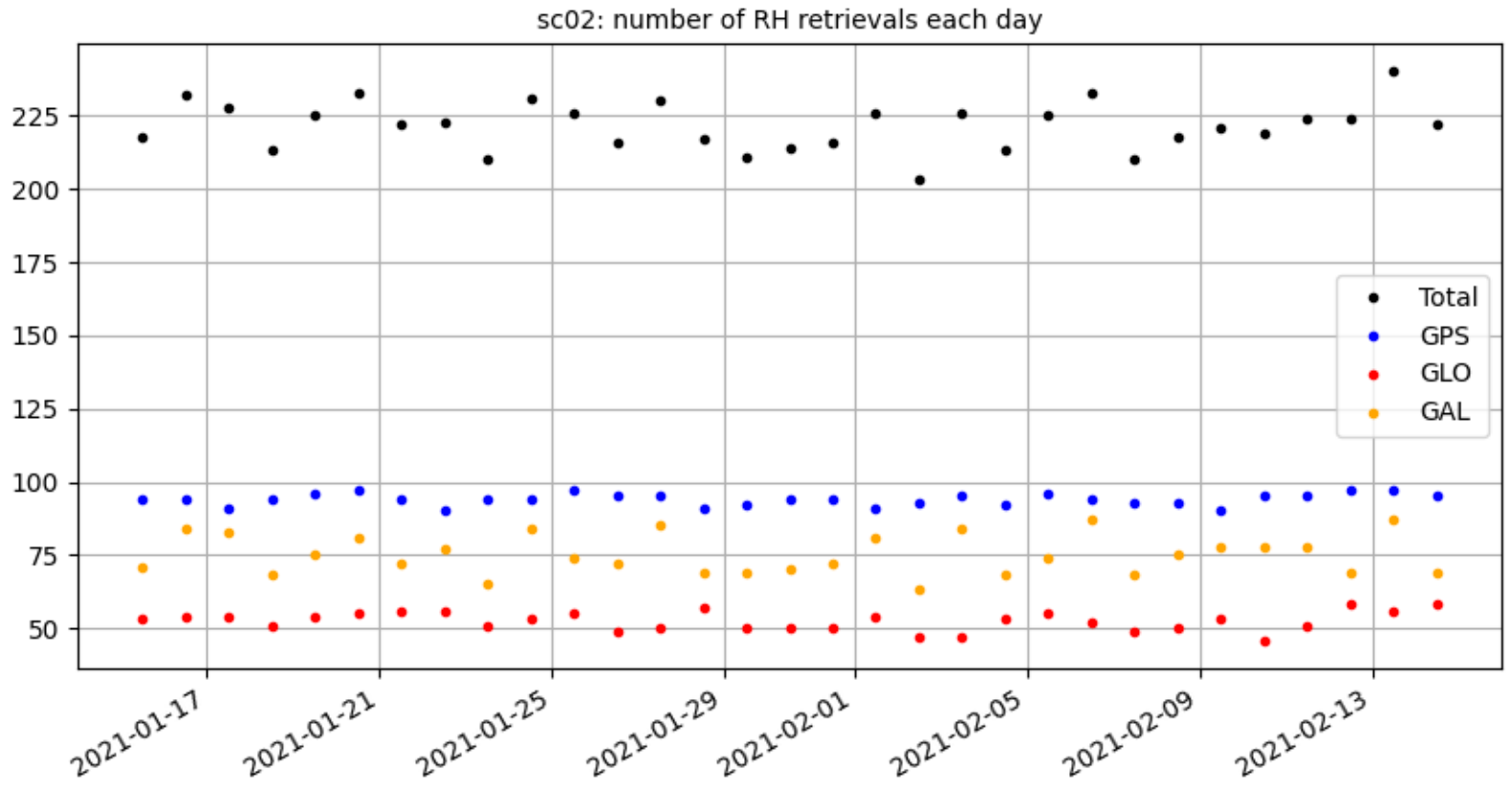
```
gnssir sc02 2021 15 -doy_end 45
```

Why don't I use Glonass L8 (f=208)? See the files and frequencies section of the documentation.

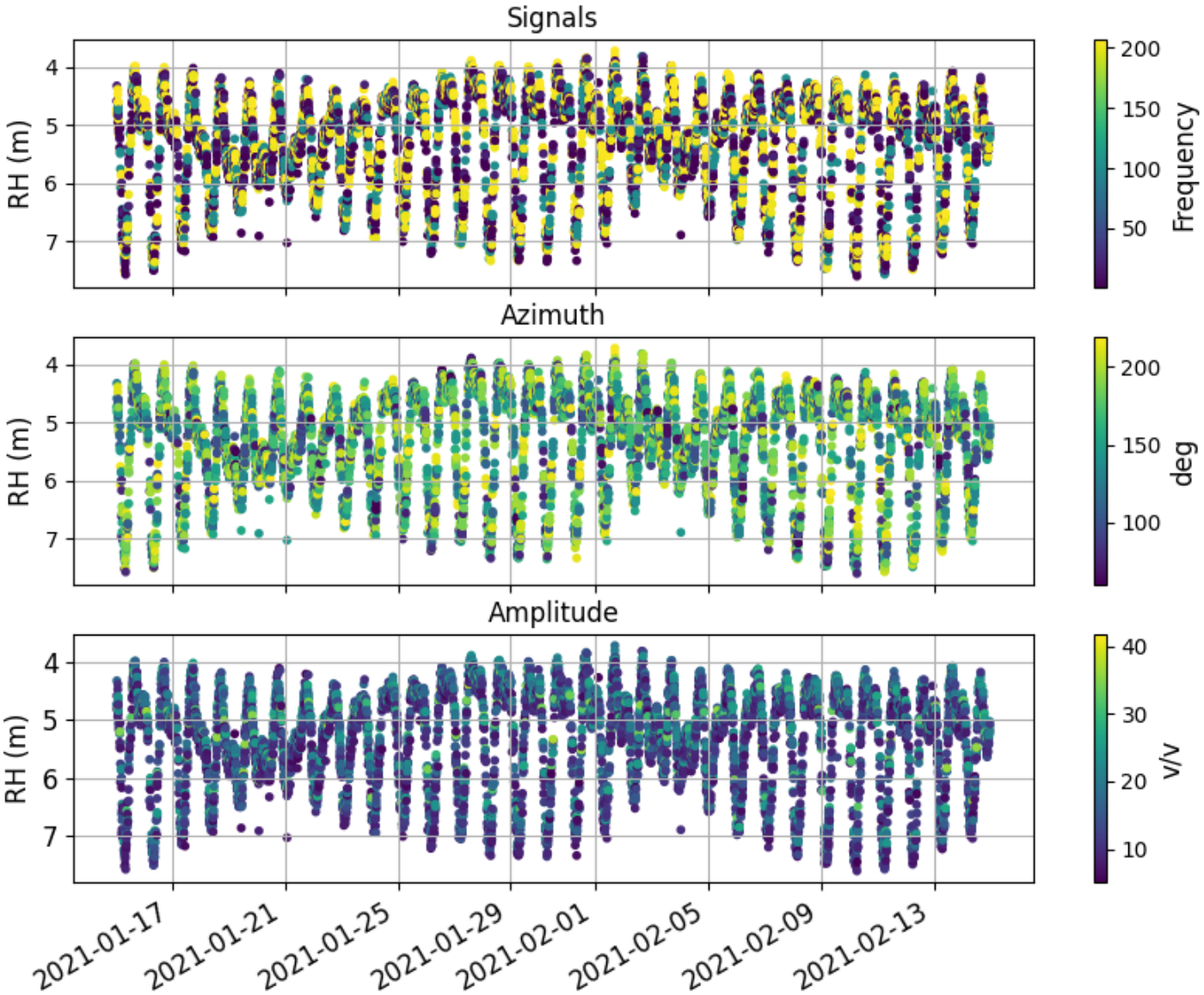
water levels: subdaily

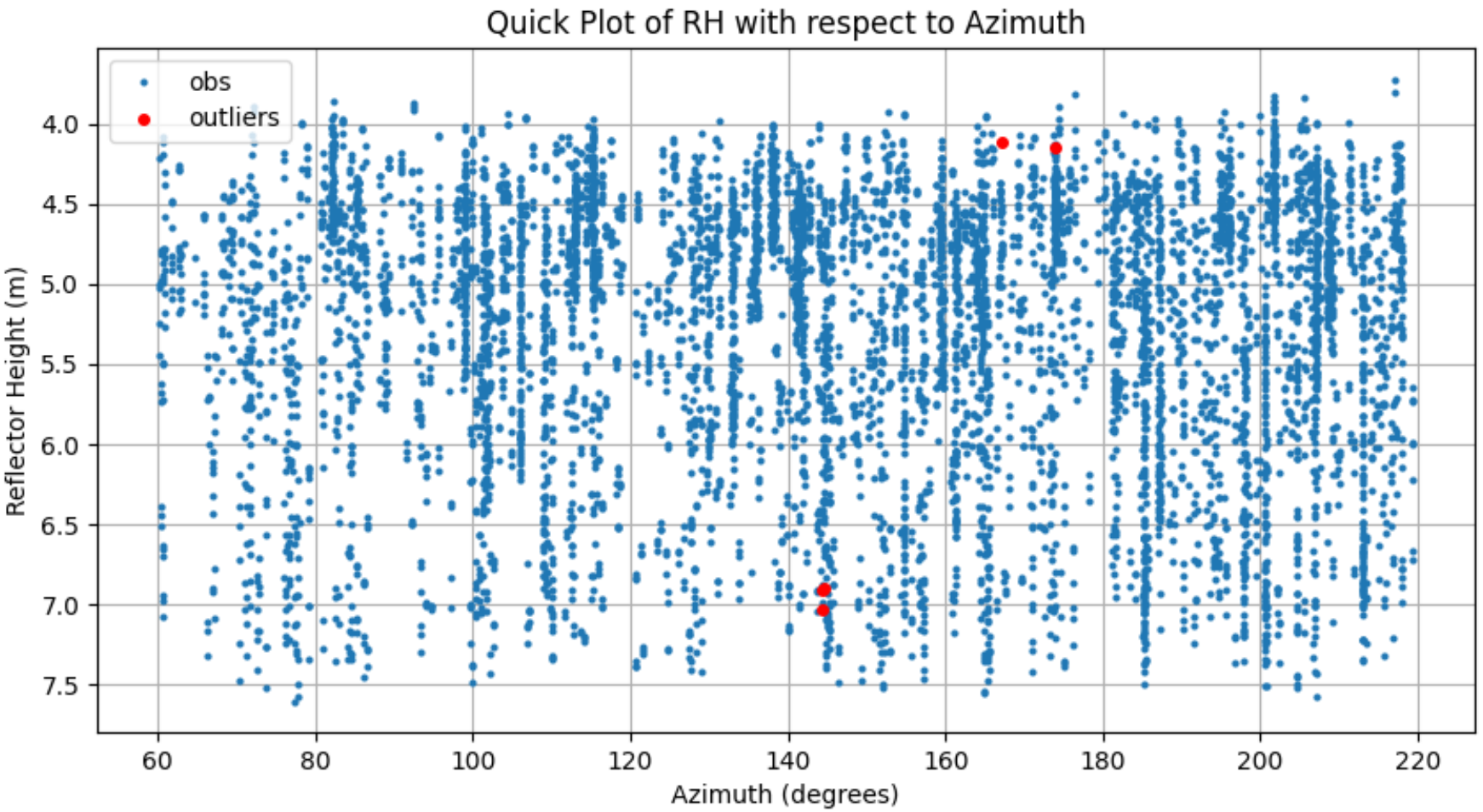
- First section is to give you feedback on your dataset.
  - Do you have a lot of outliers?
  - Should you go back and change your mask?
  - Should you apply RH restrictions?
  - Which constellations are making the biggest contribution?
- First section removes only the largest outliers (using 2.5 sigma from daily average, which can be changed on the command line).

Larson, Ray, Williams, 2017 showed ~35 measurements per day (L1 GPS).

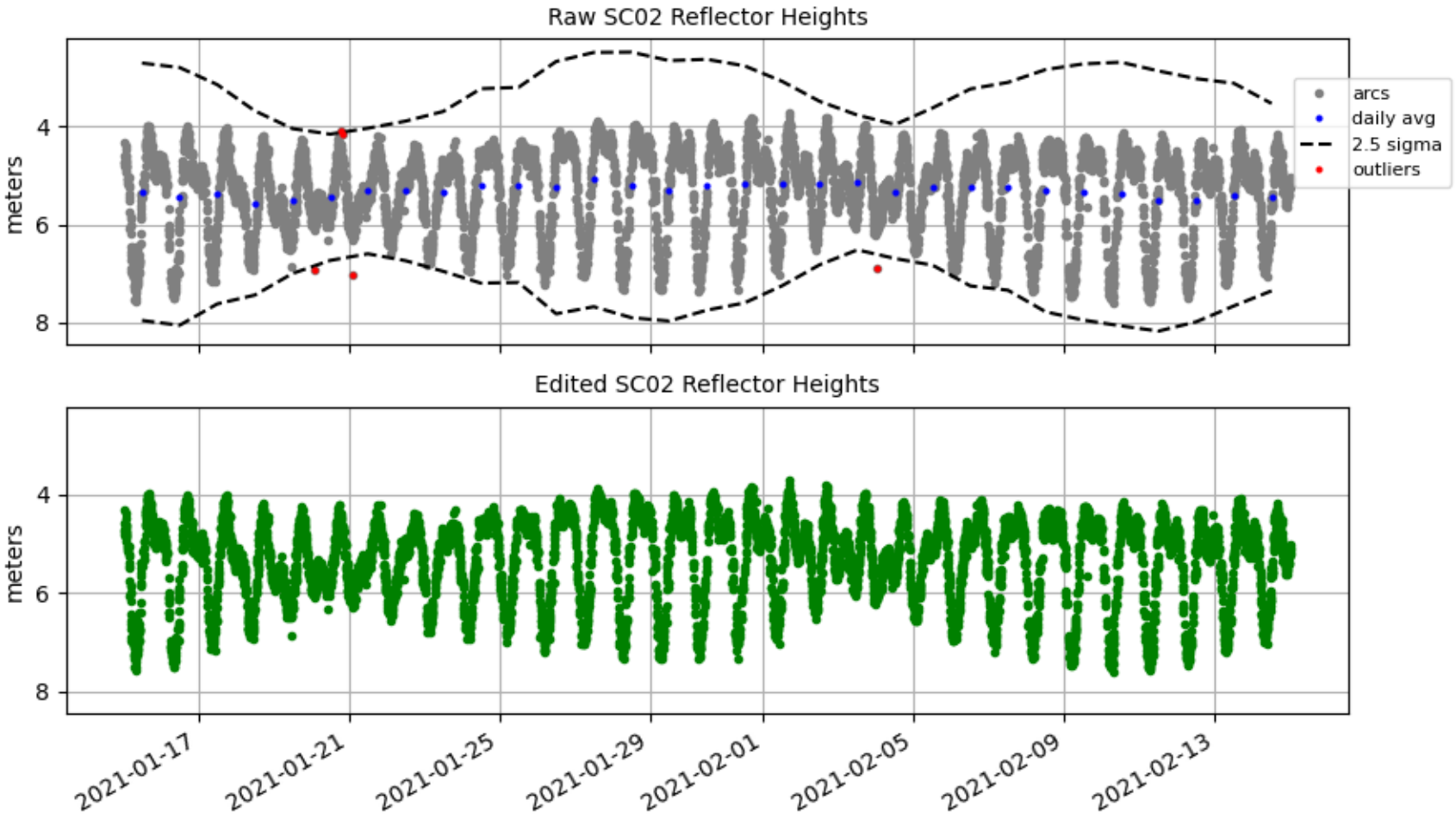


Look for any crazy azimuthal and amplitude issues




Quick Plot of RH with respect to Azimuth
obs
outliers
Reflector Height (m)
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
60
80
100
120
140
160
180
200
220
Azimuth (degrees)

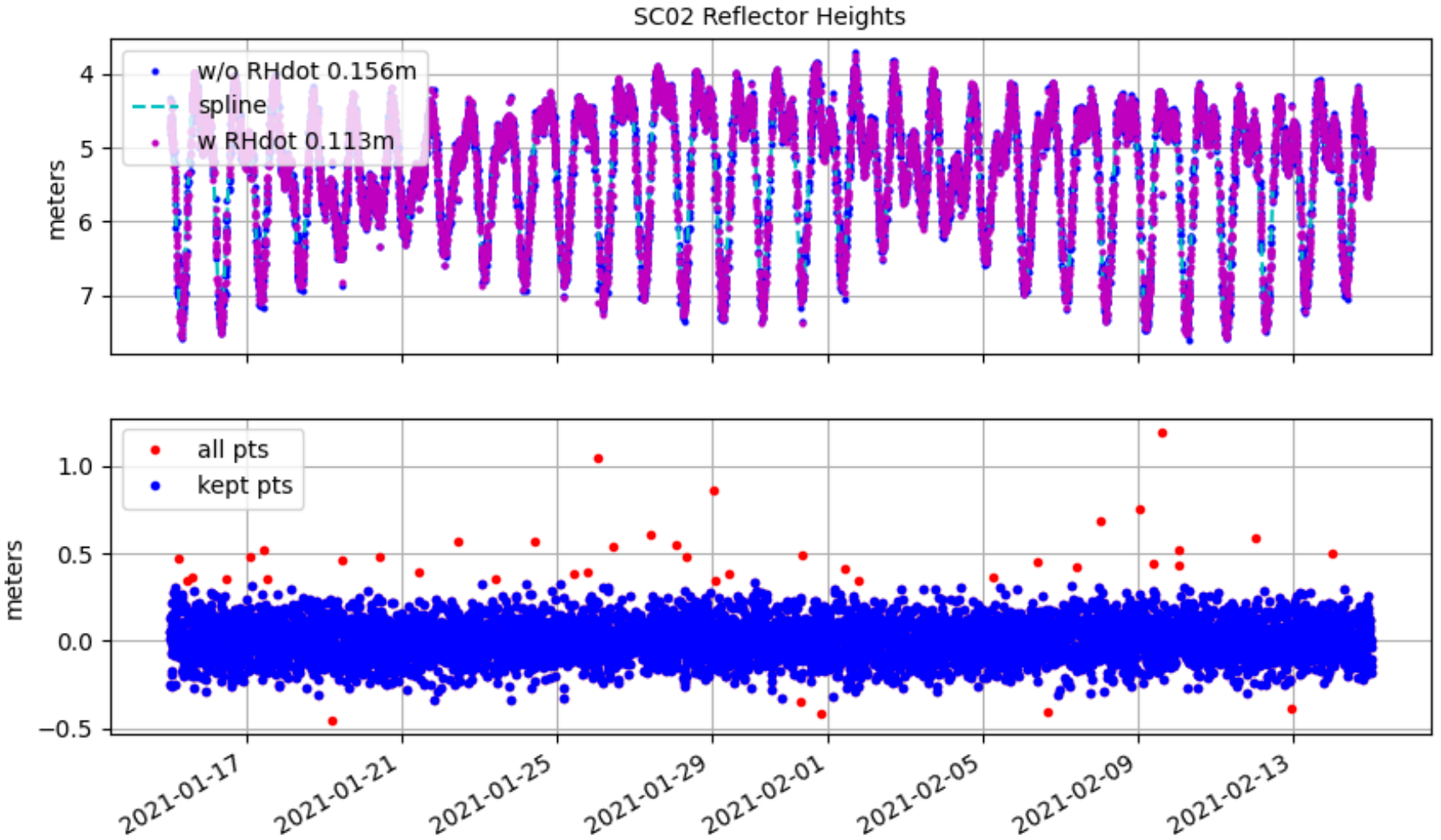
removes only a few outliers, which means our mask is pretty good



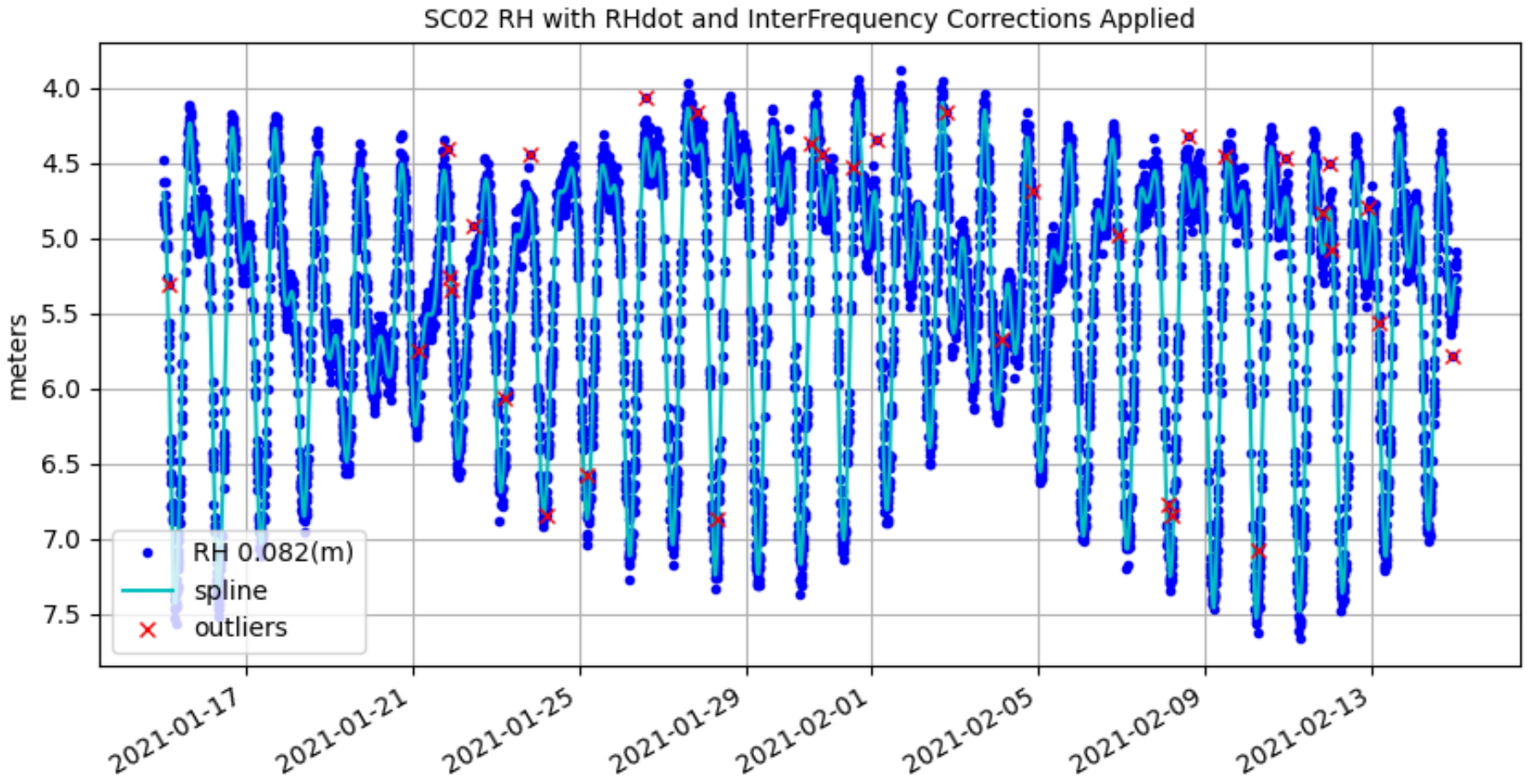
subdaily

- Second section
  - Compute and apply RHdot correction
  - a spline is used to calculate RHdot.
  - it also uses the spline to remove smaller outliers and compute and remove inter-frequency biases
- After all that, it computes a new spline.
  - creates an evenly sampled RH from that last spline, but IT IS A SPLINE FIT. it is not the truth.
    - a spline is smooth and not all water measurements have smooth behavior
  - you control the spline - by setting the number of knots on the command line.

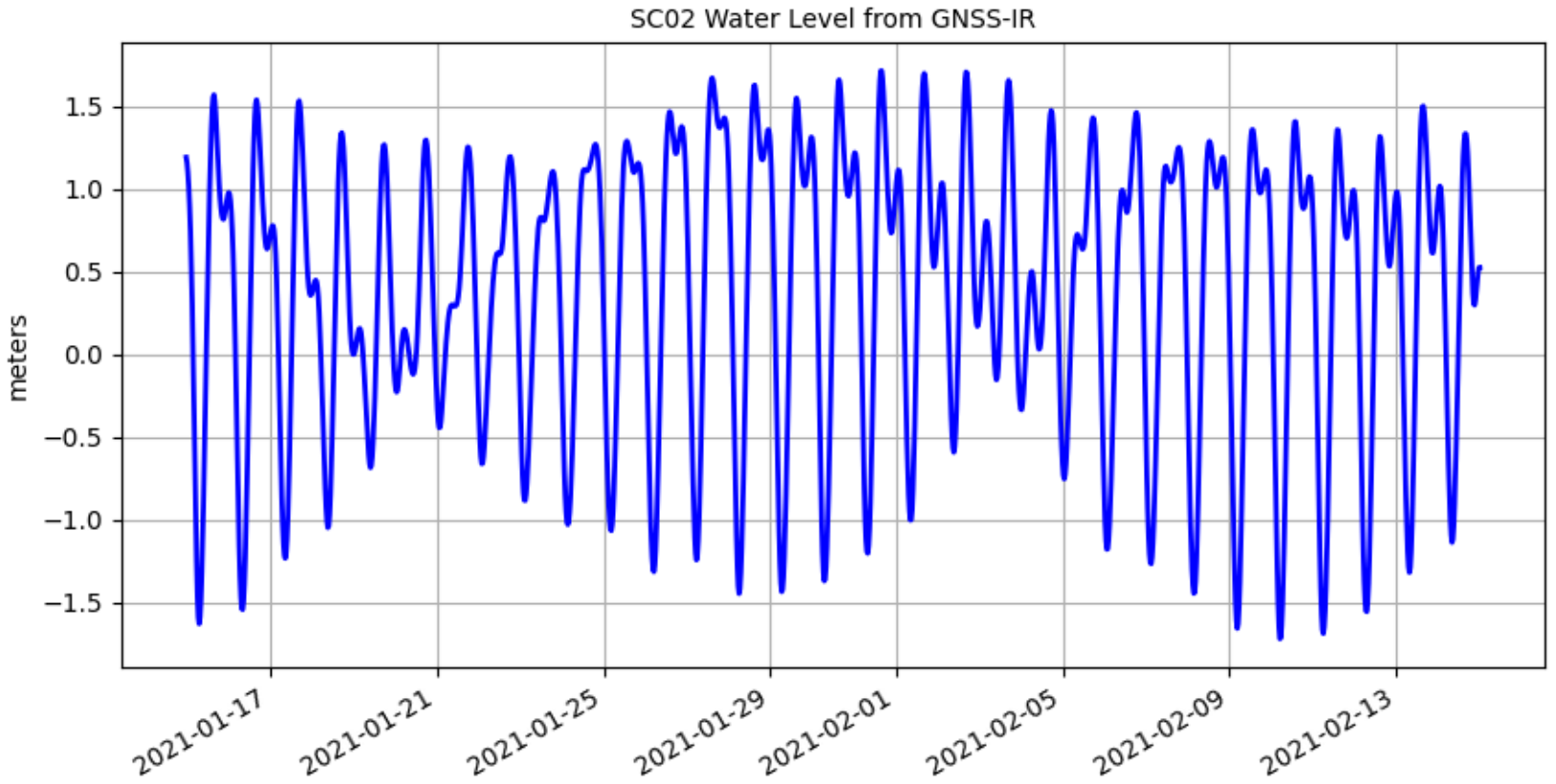
1. fit a spline
2. compute/apply RHdot.
3. Report RMS with and without that correction.
4. Remove 3 sigma outliers



1. Compute/remove Inter-frequency biases
2. Compute new RMS, identify outliers (red crosses)

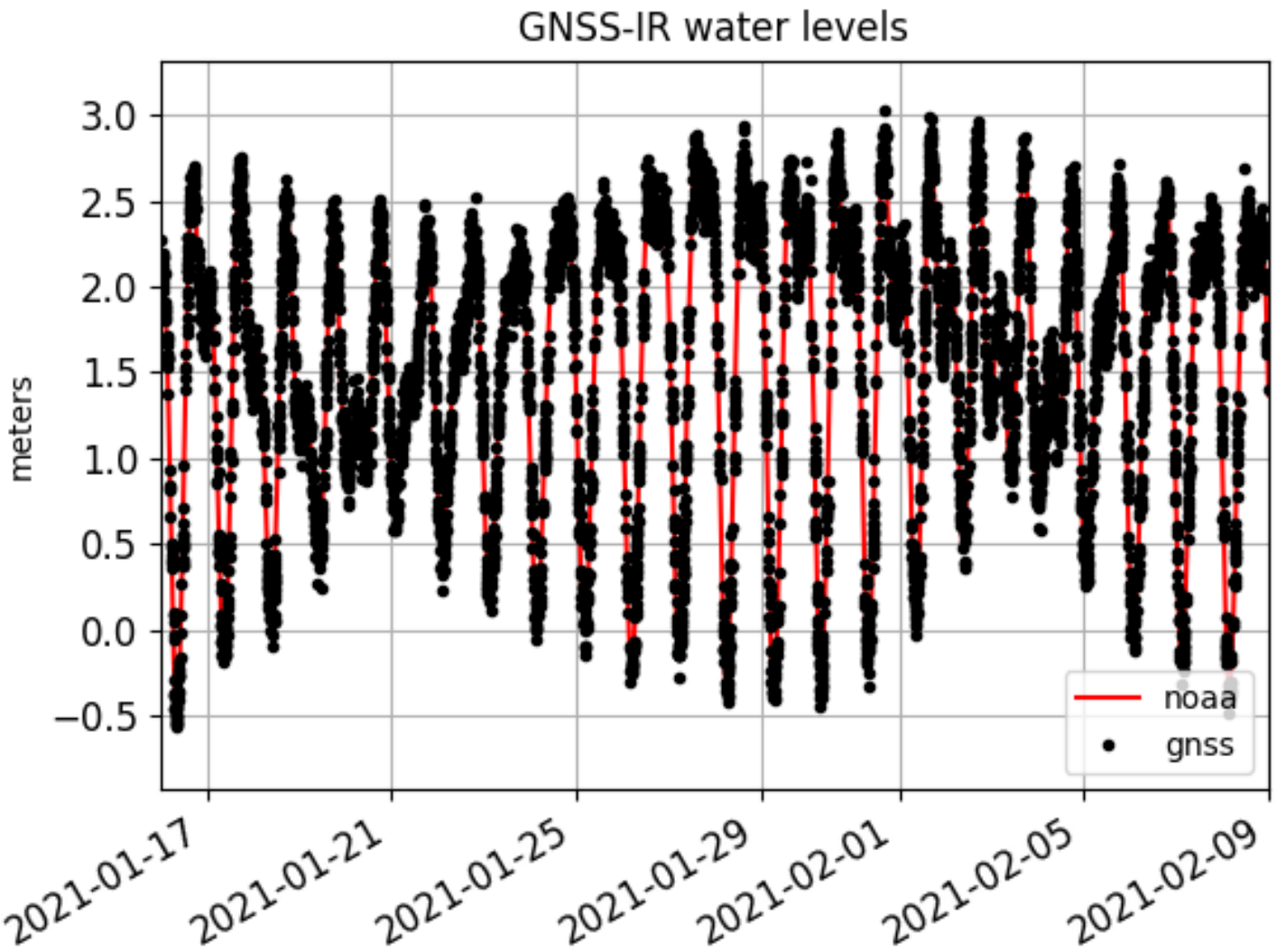


1. fit spline - write out evenly space data based on user request
2. Use orthometric height using ellipsoidal height and EGM96. You control this!

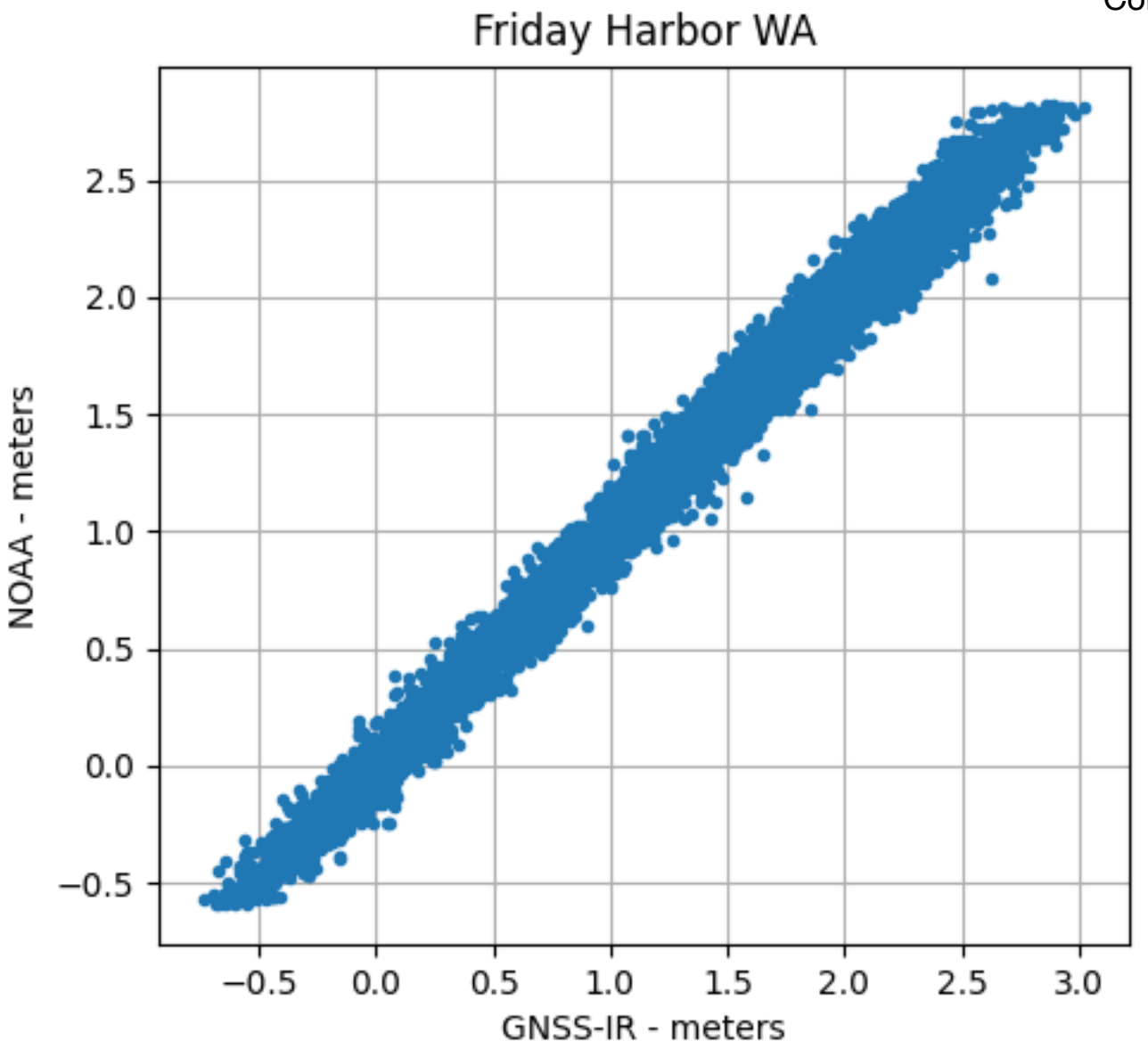


How to define reflector heights in ITRF is an unresolved issue. Are you going to include the slope of the station's height? But adding an orthometric height to the code is a start.

Accuracy: NOAA runs a tide gauge very close to SC02



Correlation is ~0.994



Does GNSS-IR work at taller sites?

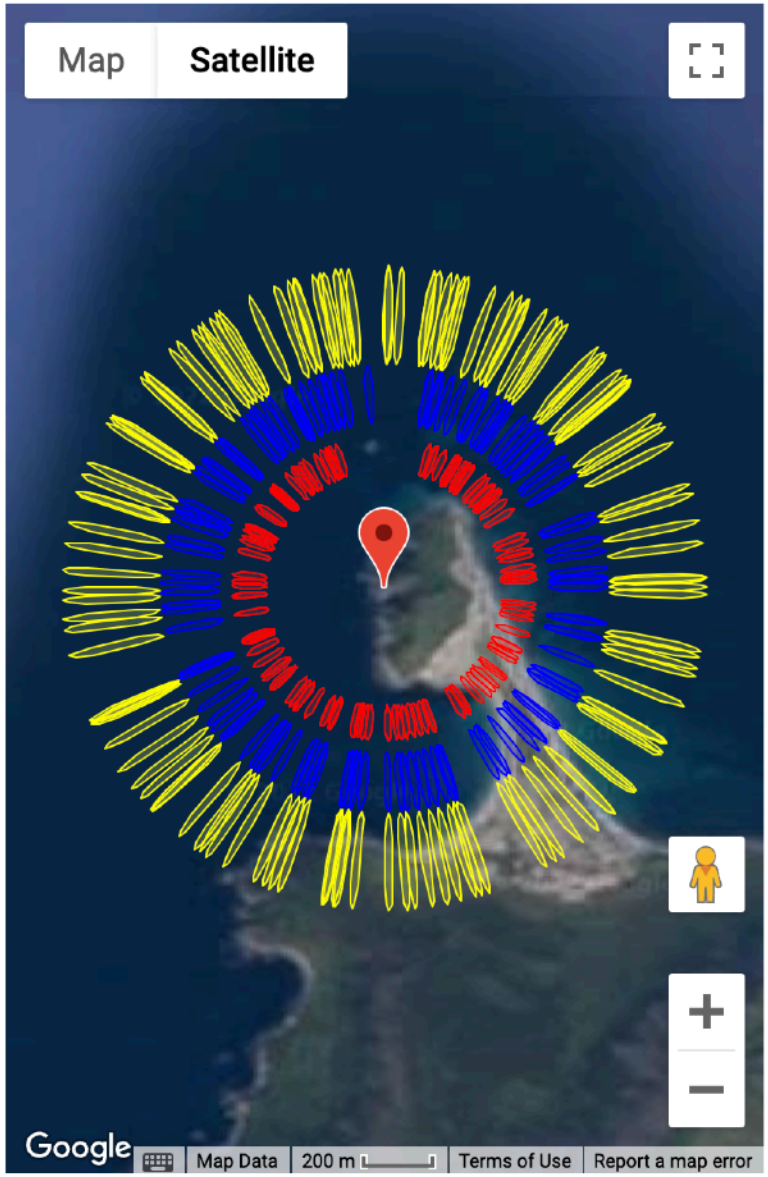
ac12

find proper azimuths using refl_zones module or https://gnss-reflections.org/rzones

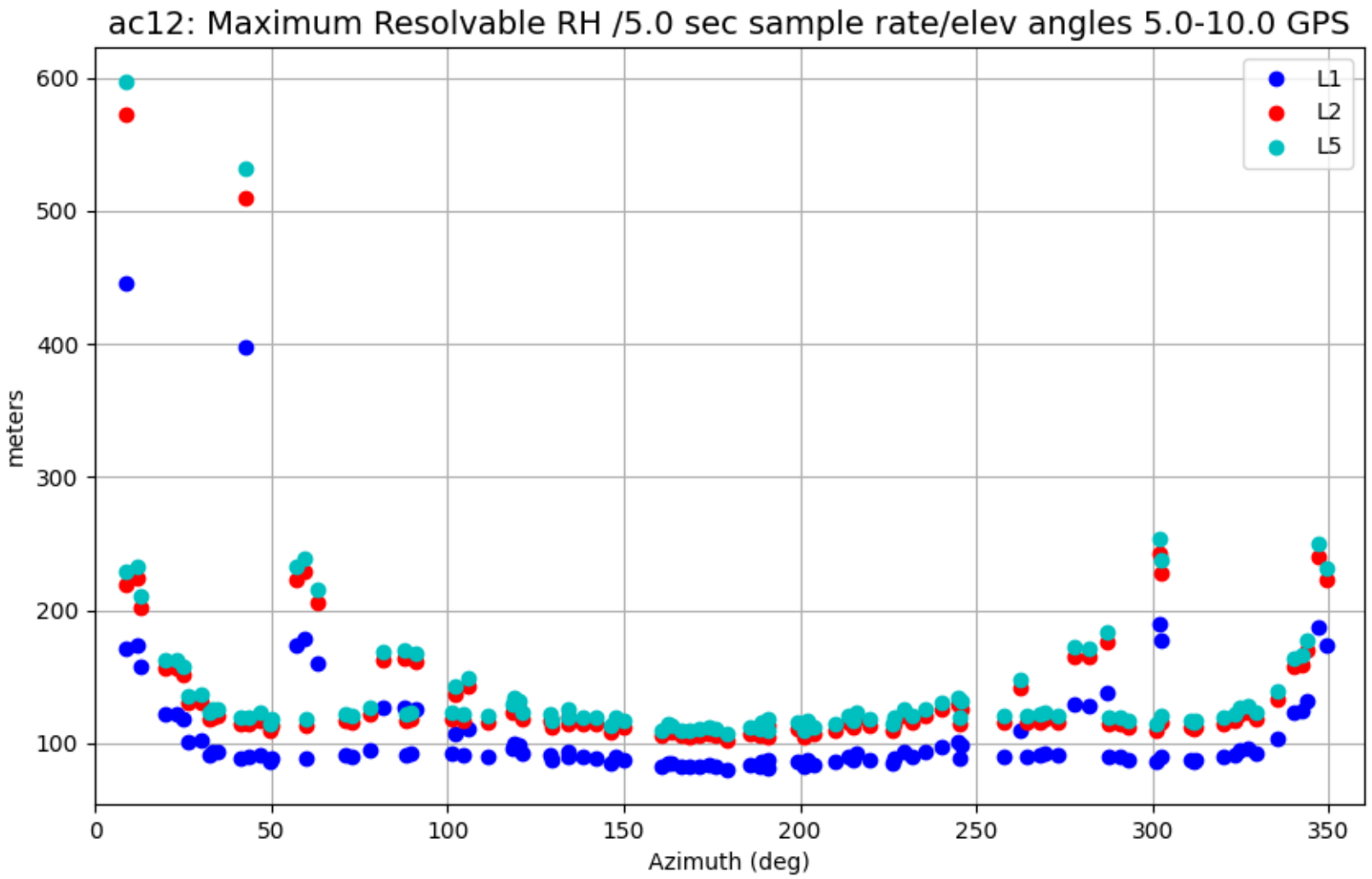
Note the difficulties to the south

These Fresnel zones are 5-7-10 degrees.

Reflection Height is reported as 68 meters



What sampling rate is required? Try out 5 seconds



```
rinex2snr ac12 2020 205 -dec 2 -snr 50 -archive unavco -rate high
```

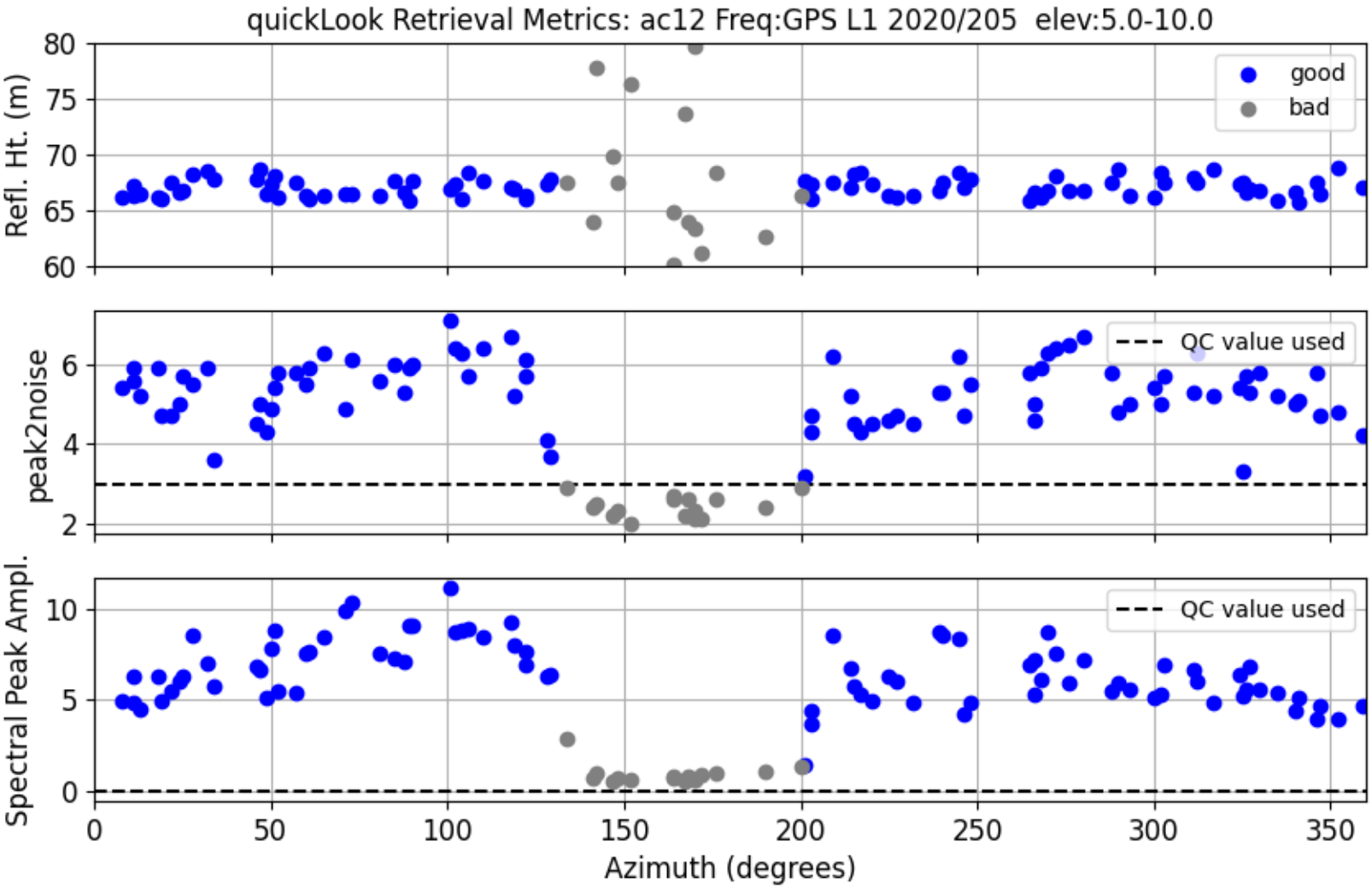
snr 50 is special mode where you only keep data below elevation angles of 10 degrees.

Since the code uses snr=66 as the default, you will need to specify snr of 50 in *quickLook* and *gnssir*

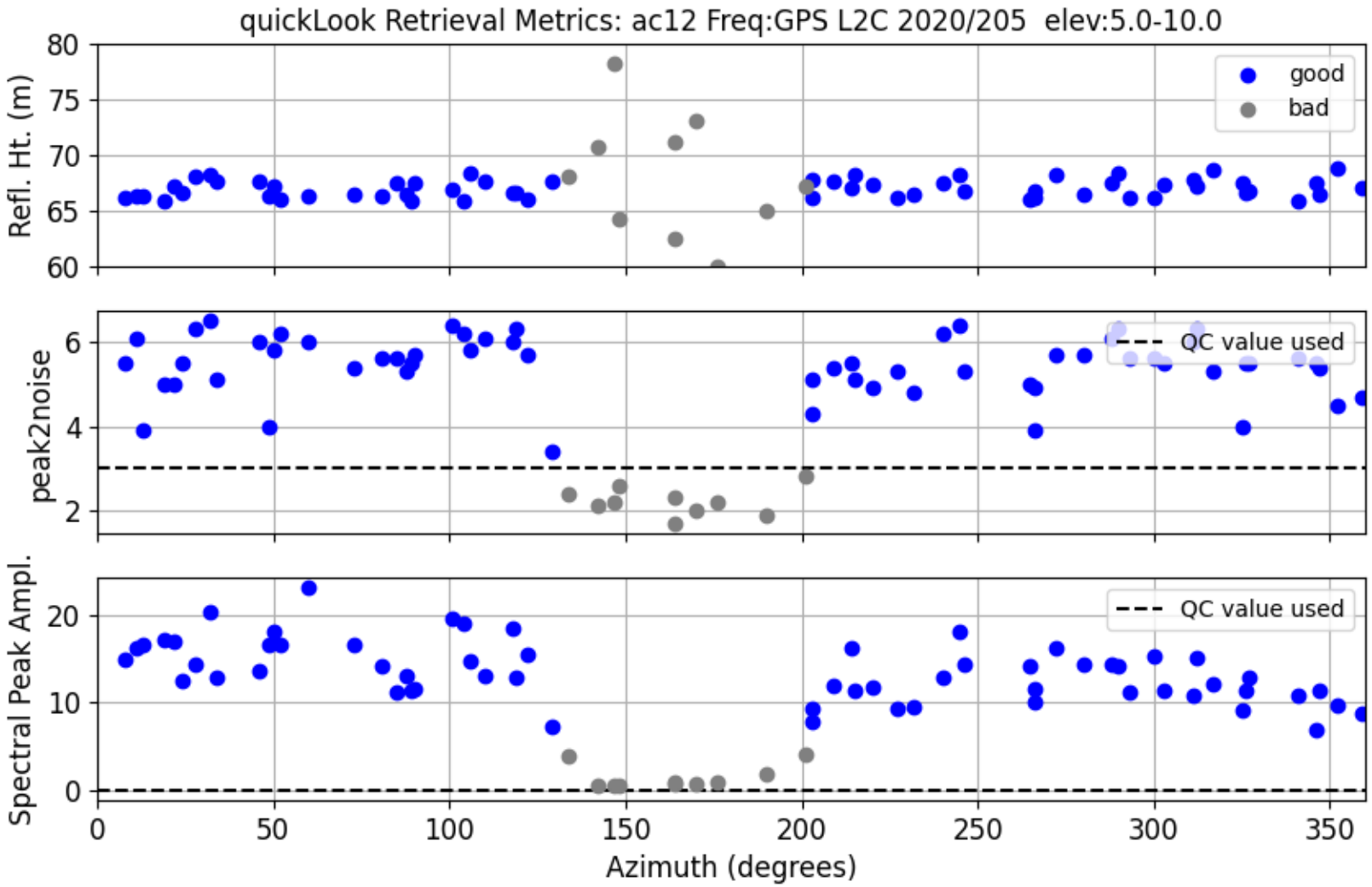
You can decimate at either the *rinex2snr* stage or when running *gnssir*.

Turning off amplitude limit because I am not sure what it should be

```
quickLook ac12 2020 205 -snr 50 -h1 60 -h2 80 -e1 5 -e2 10 -ampl 0
```



L2C even better … peak2noise of 4 looks ok? Continue turning off amplitude



Note: absolute RH values from quickLook are not the same as gnssir because there is no refraction model in quickLook. Because it is a quick look.

Make more SNR files using rinex2snr

```
rinex2snr ac12 2020 183 -doy_end 197 -snr 50 -archive unavco -rate high -dec 2
```

Receiver was L1 and L2 GPS only at this time, so no point listing other frequencies
Notice how I split the azimuth regions.

```
gnssir_input ac12  -e1 5 -e2 10 -h1 60 -h2 80-azlist2 0 125 200 360 -frlist 1 20
-ampl 0 -peak2noise 4
```

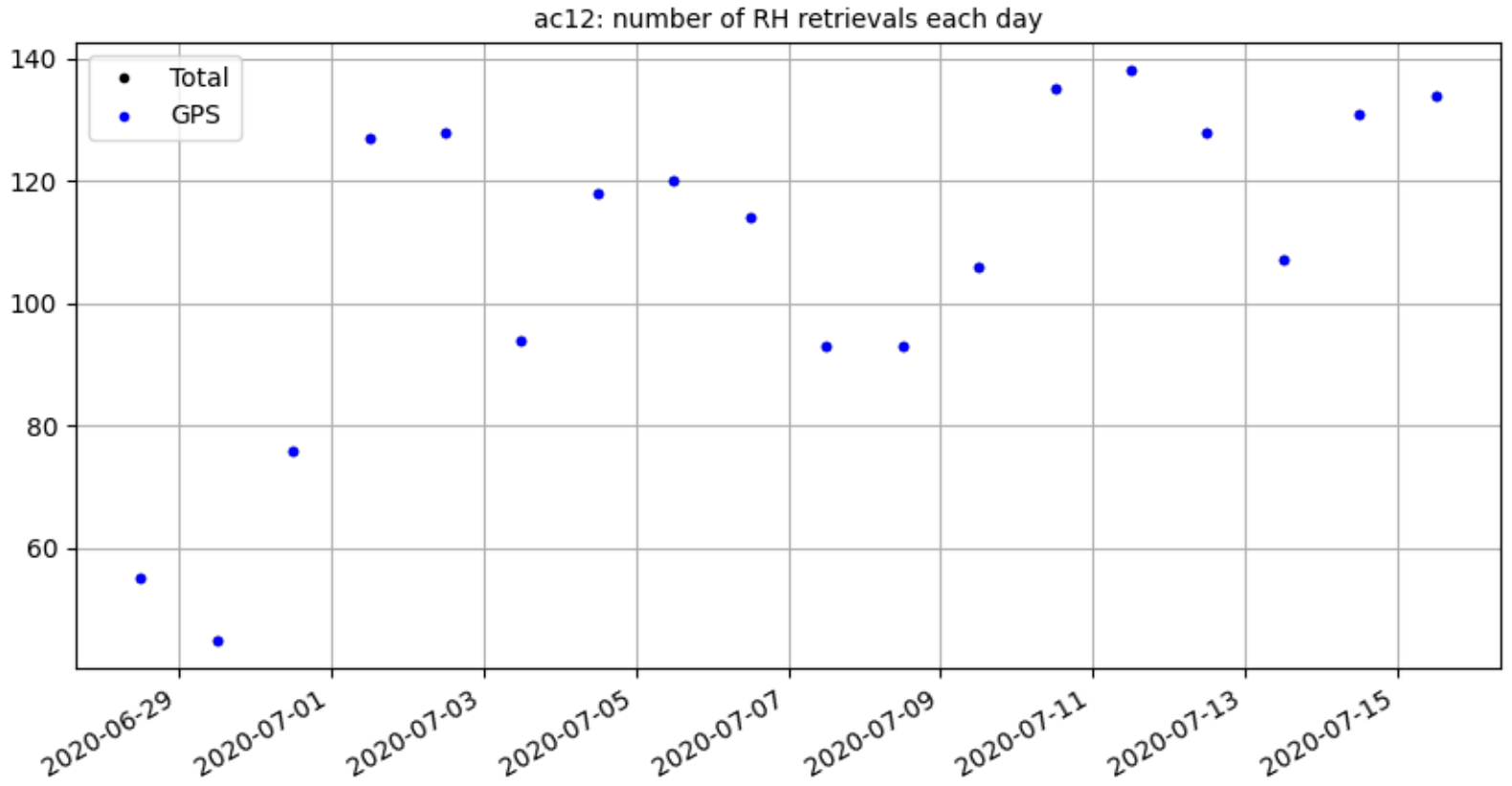
The choices are all made earlier, so the gnssir command is very simple

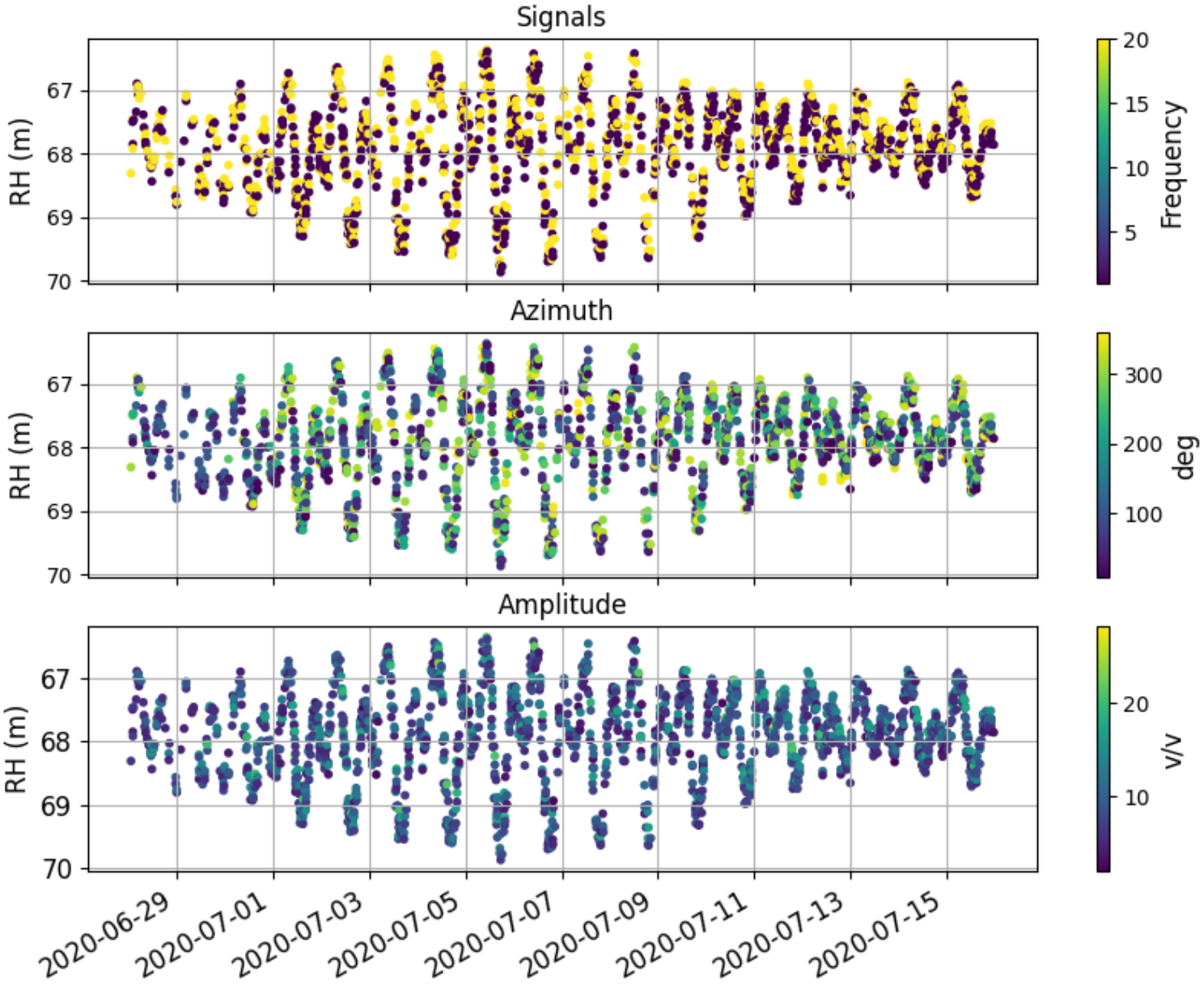
```
gnssir ac12 2020 183 -snr 50 -doy_end 197
```

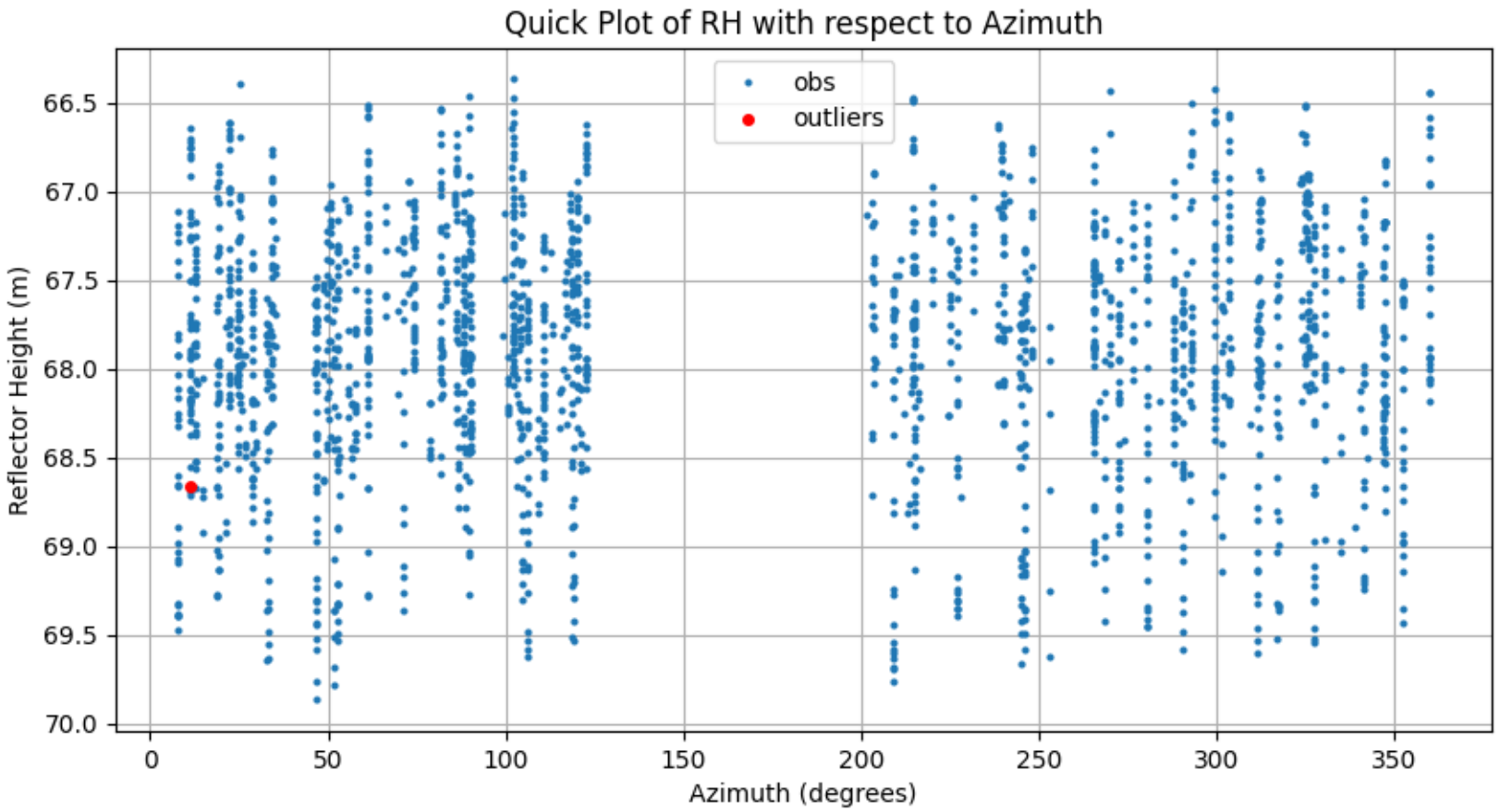
Now consolidate the results

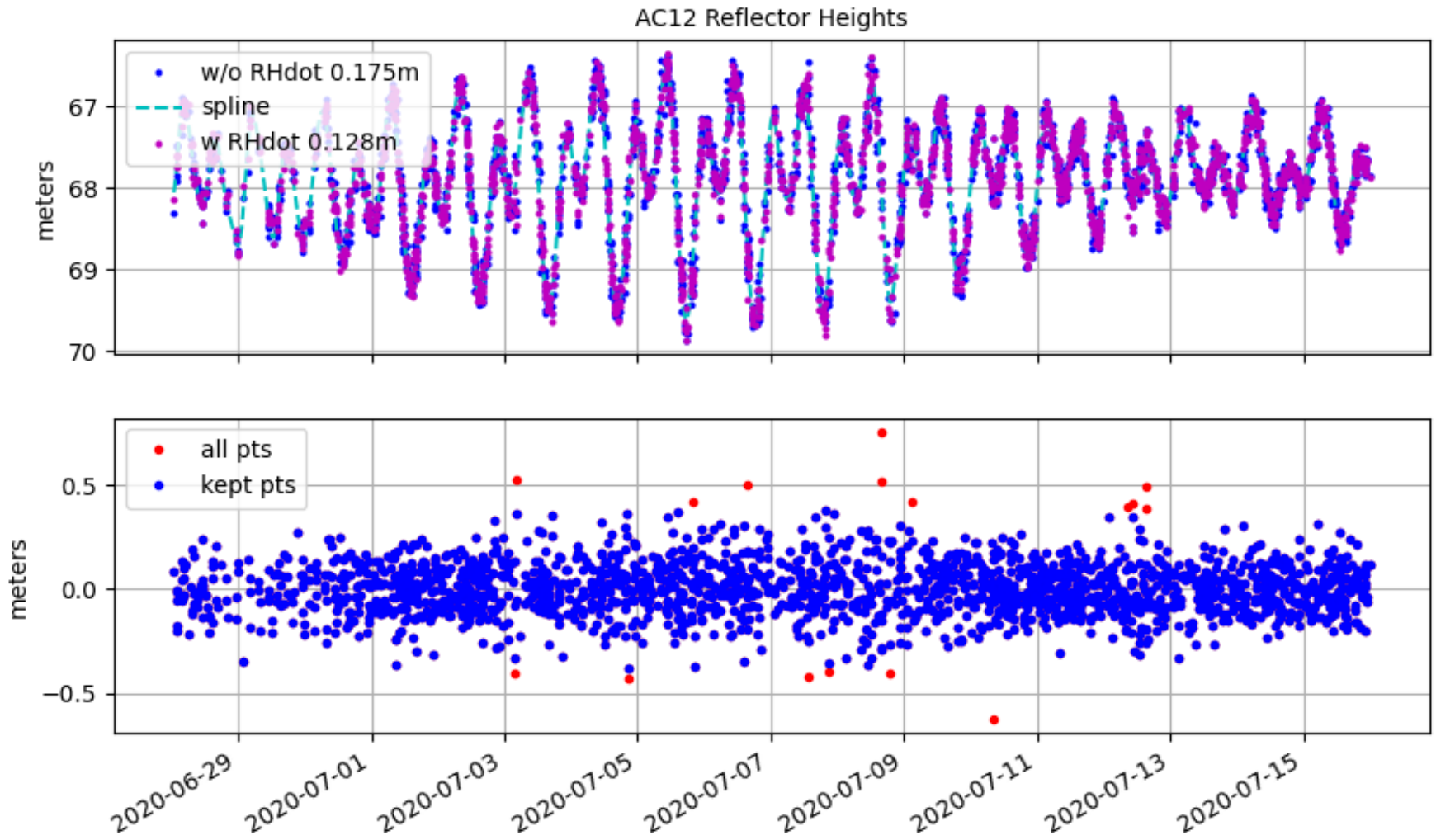
```
subdaily ac12 2020
```

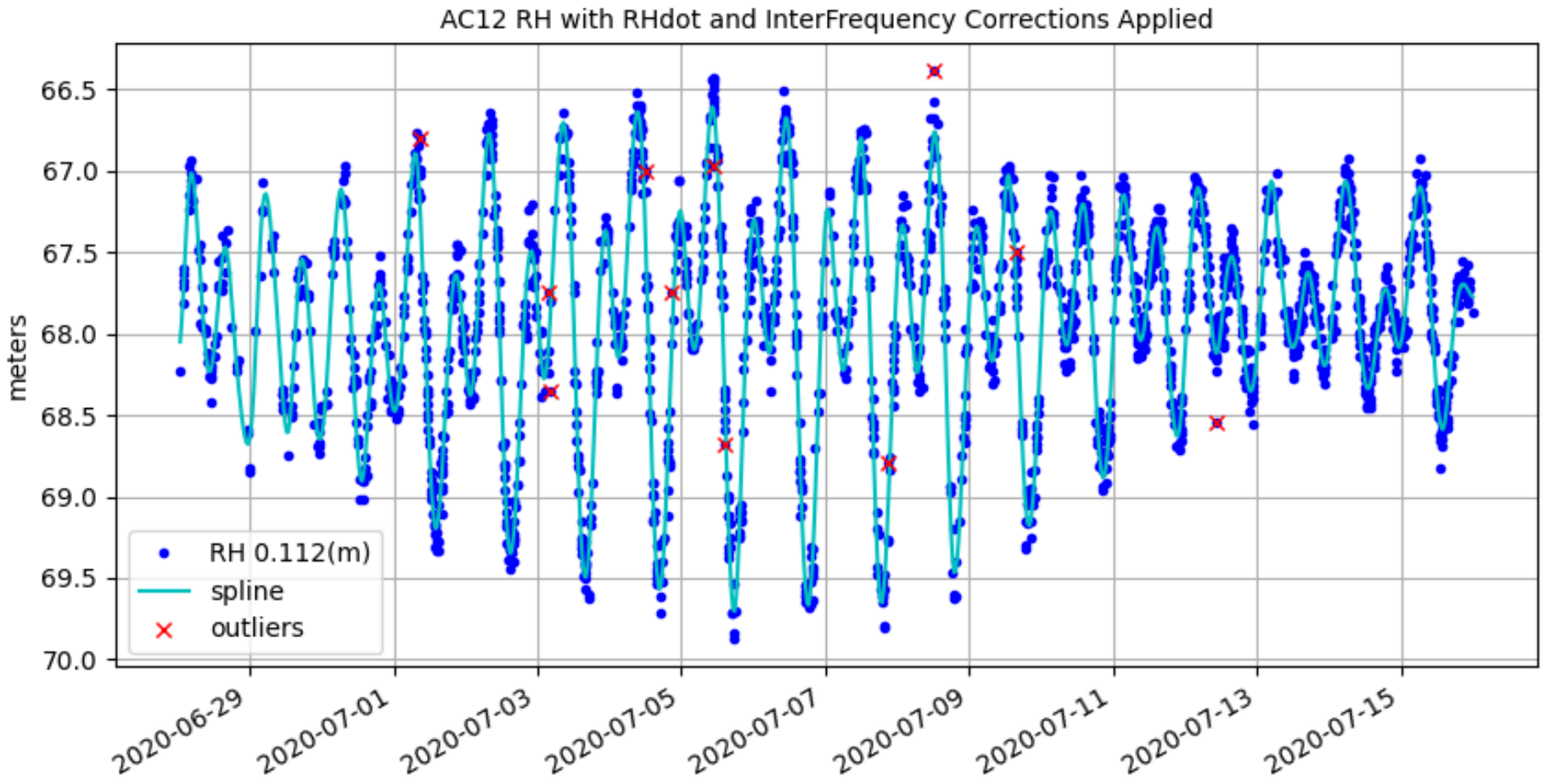
At sc02 we had more than 220 measurements per day. No such luck at ac12. We only have L1 and L2C in 2020.




Signals
Azimuth
Amplitude
RH (m)
67
68
69
70
Frequency
20
15
10
5
deg
300
200
100
v/v
20
10
2020-06-29
2020-07-01
2020-07-03
2020-07-05
2020-07-07
2020-07-09
2020-07-11
2020-07-13
2020-07-15


Quick Plot of RH with respect to Azimuth
obs
outliers
Reflector Height (m)
66.5
67.0
67.5
68.0
68.5
69.0
69.5
70.0
0
50
100
150
200
250
300
350
Azimuth (degrees)


AC12 Reflector Heights
w/o RHdot 0.175m
spline
w RHdot 0.128m
meters
67
68
69
70
all pts
kept pts
meters
0.5
0.0
−0.5
2020-06-29
2020-07-01
2020-07-03
2020-07-05
2020-07-07
2020-07-09
2020-07-11
2020-07-13
2020-07-15


AC12 RH with RHdot and InterFrequency Corrections Applied
meters
66.5
67.0
67.5
68.0
68.5
69.0
69.5
70.0
RH 0.112(m)
spline
outliers
2020-06-29
2020-07-01
2020-07-03
2020-07-05
2020-07-07
2020-07-09
2020-07-11
2020-07-13
2020-07-15

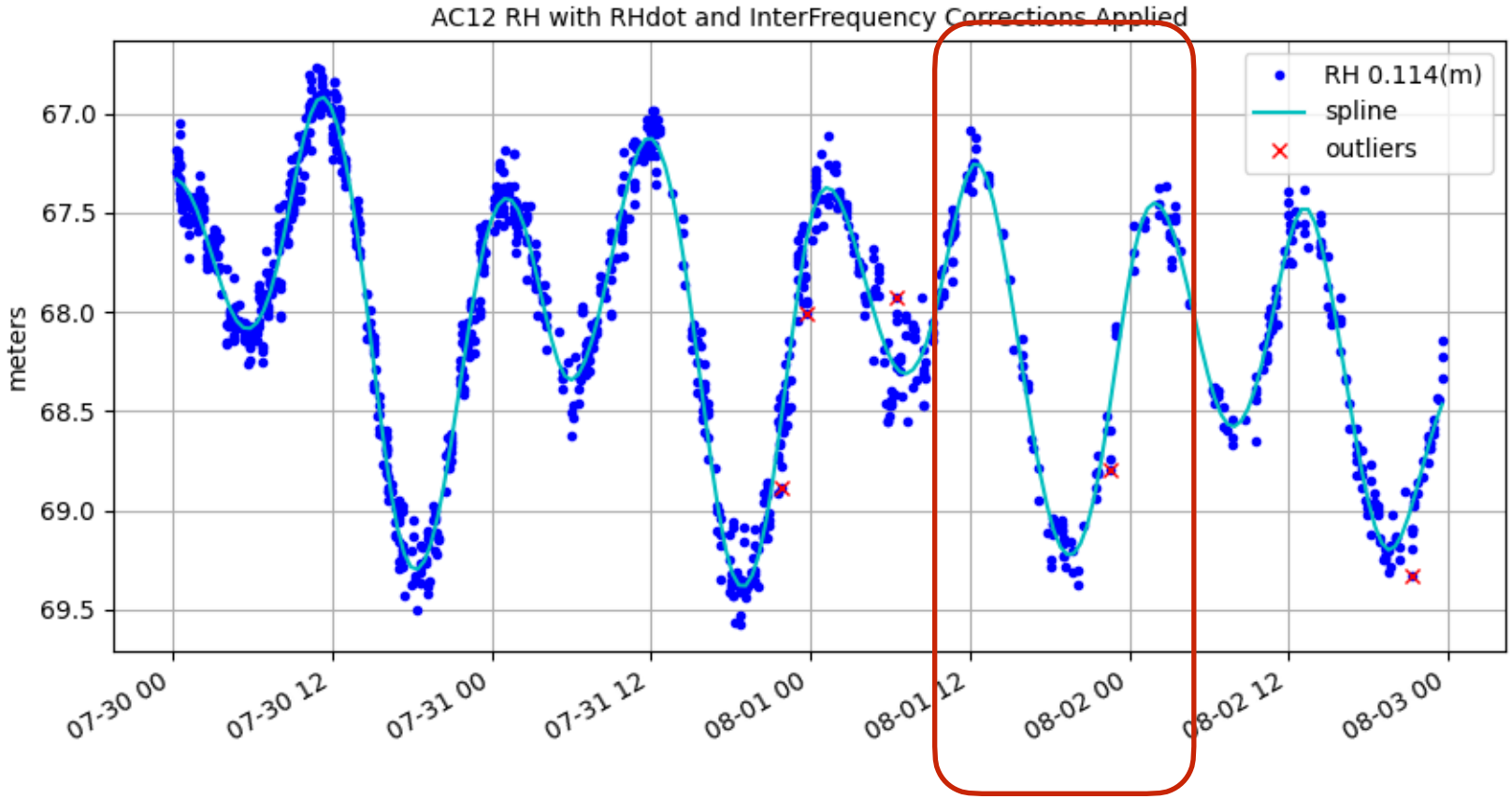
with these tall sites, you can try using subarcs to estimate RH

but when you do that, your peak2noise value might need to change. and the max allowed length of your arcs should probably be shortened.

How to explore? use *gnssir_input* -extension test (or another name of your choosing) and you can put a different strategy in it.

Use -extension test when you run *gnssir* and *subdaily*, and your results will be saved in a different folder called “test”

I analyzed a few days of data with a modern multiGNSS receiver — there are a lot more RH retrievals - but …

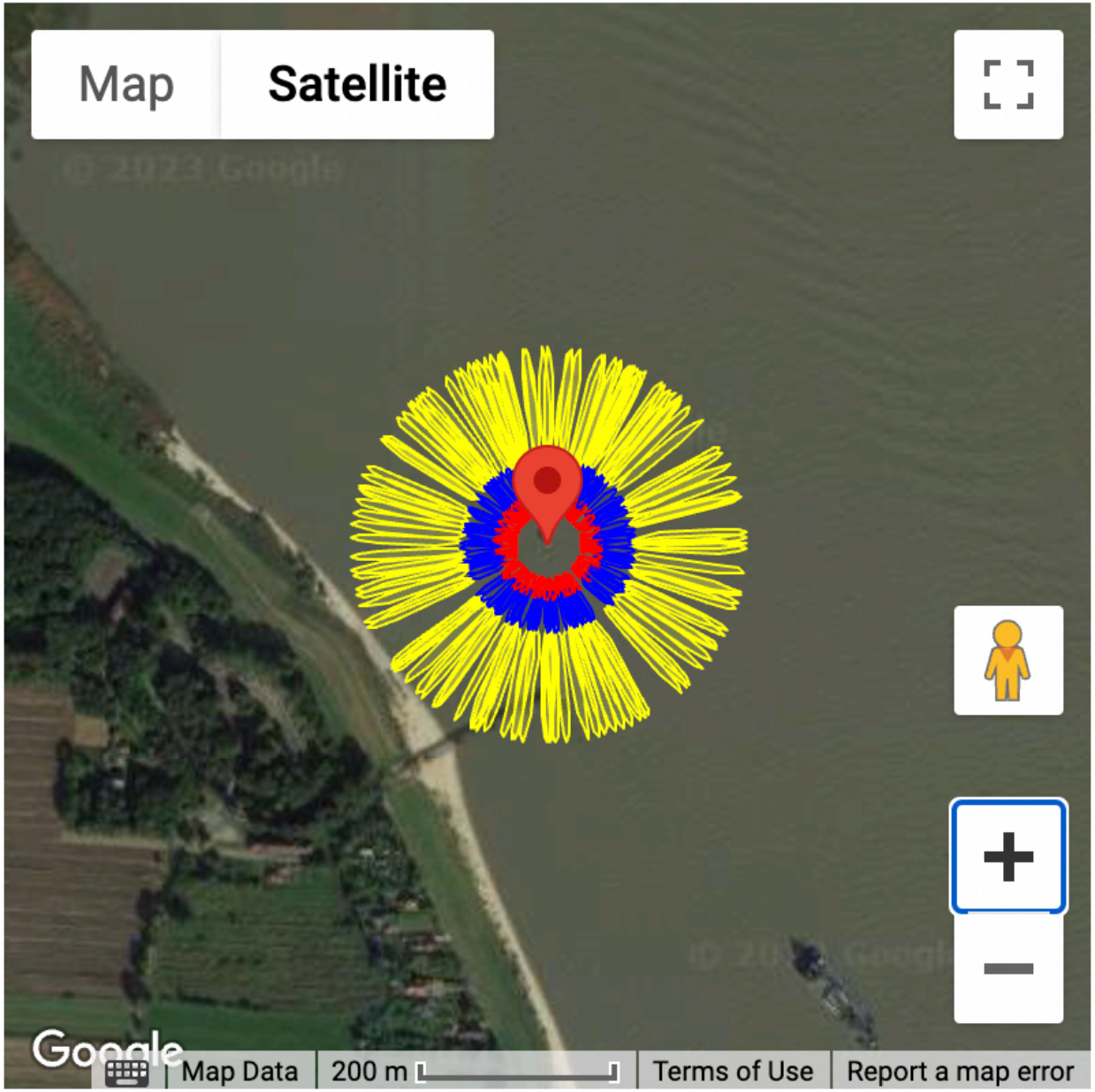


why? see Simon's presentation

Can we compare AC12 retrievals with a traditional tide gauge?

- No - because this is the only one in this part of Alaska.

River site with tidal signals


Map
Satellite
© 2023 Google
Google
Map Data
200 m
Terms of Use
Report a map error

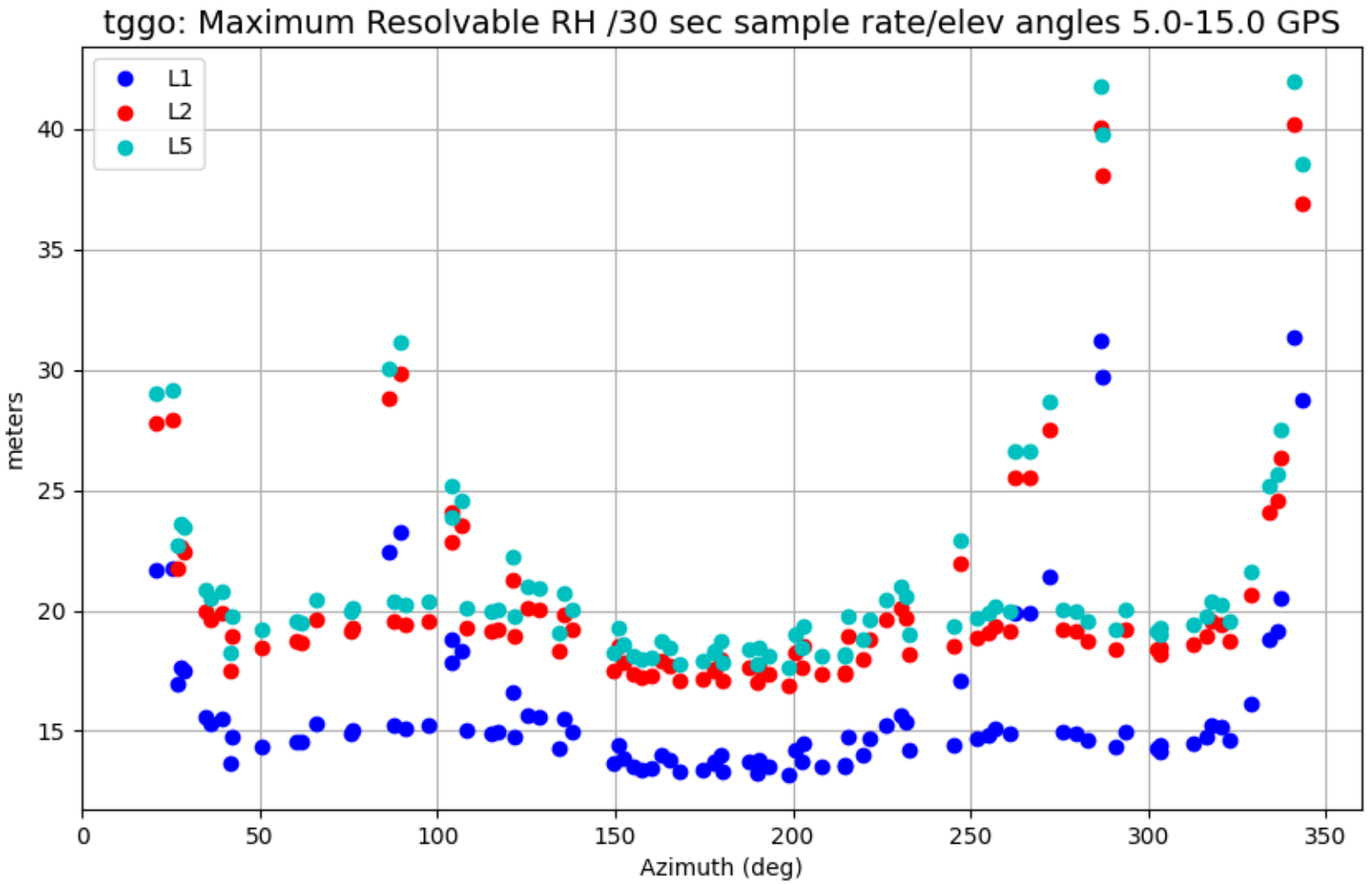
Use RINEX 3 for access to the best signals

- station tggo00deu (the longer station name will tell the code to find RINEX 3 instead of RINEX 2.11)
- archive bfg
- orb rapid (you can also use gnss if you prefer)
- samplerate 15

```
rinex2snr tggo00deu 2022 234 -archive bfg -orb rapid -samplerate 15
```

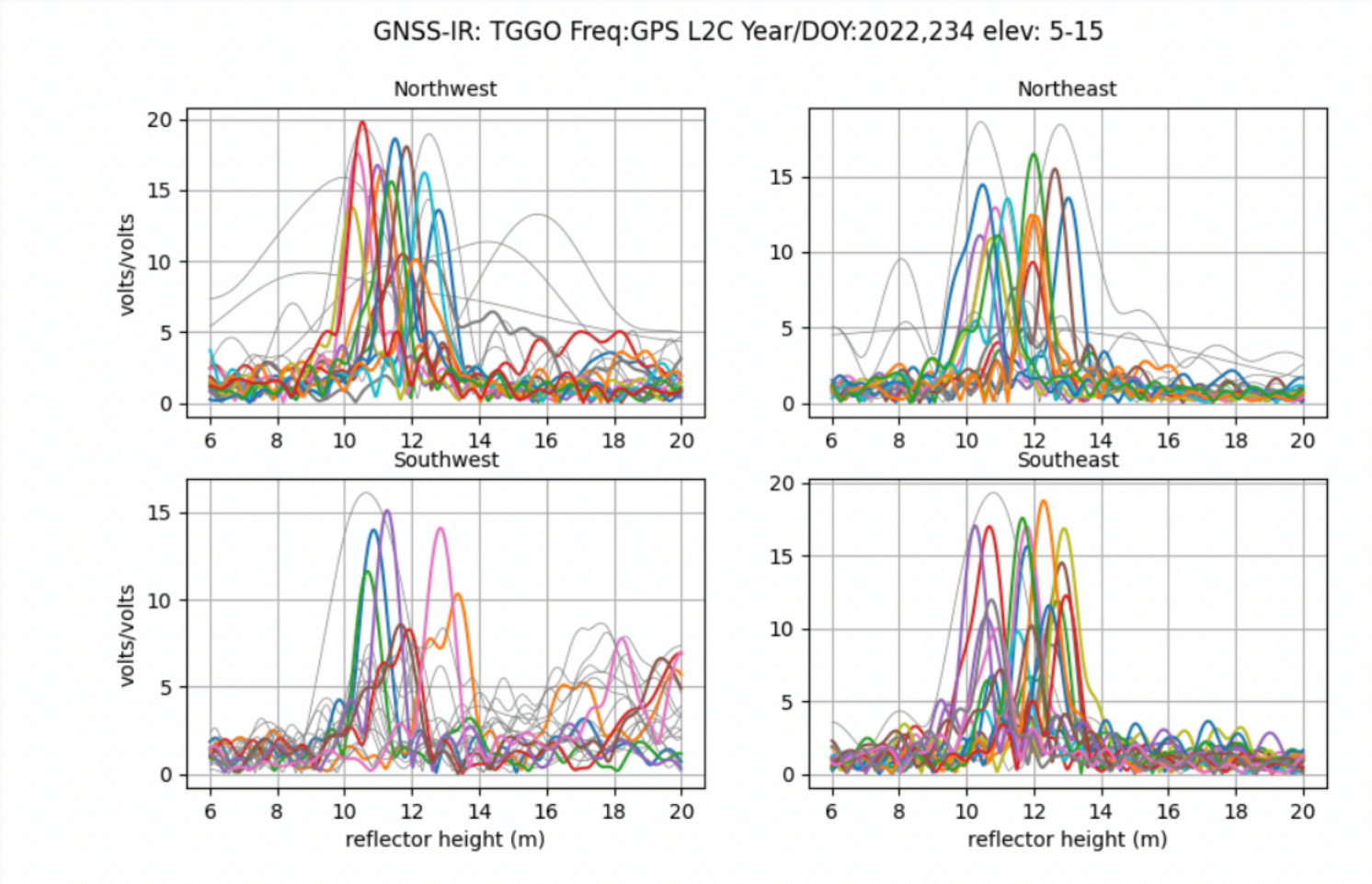
Why 15 seconds?

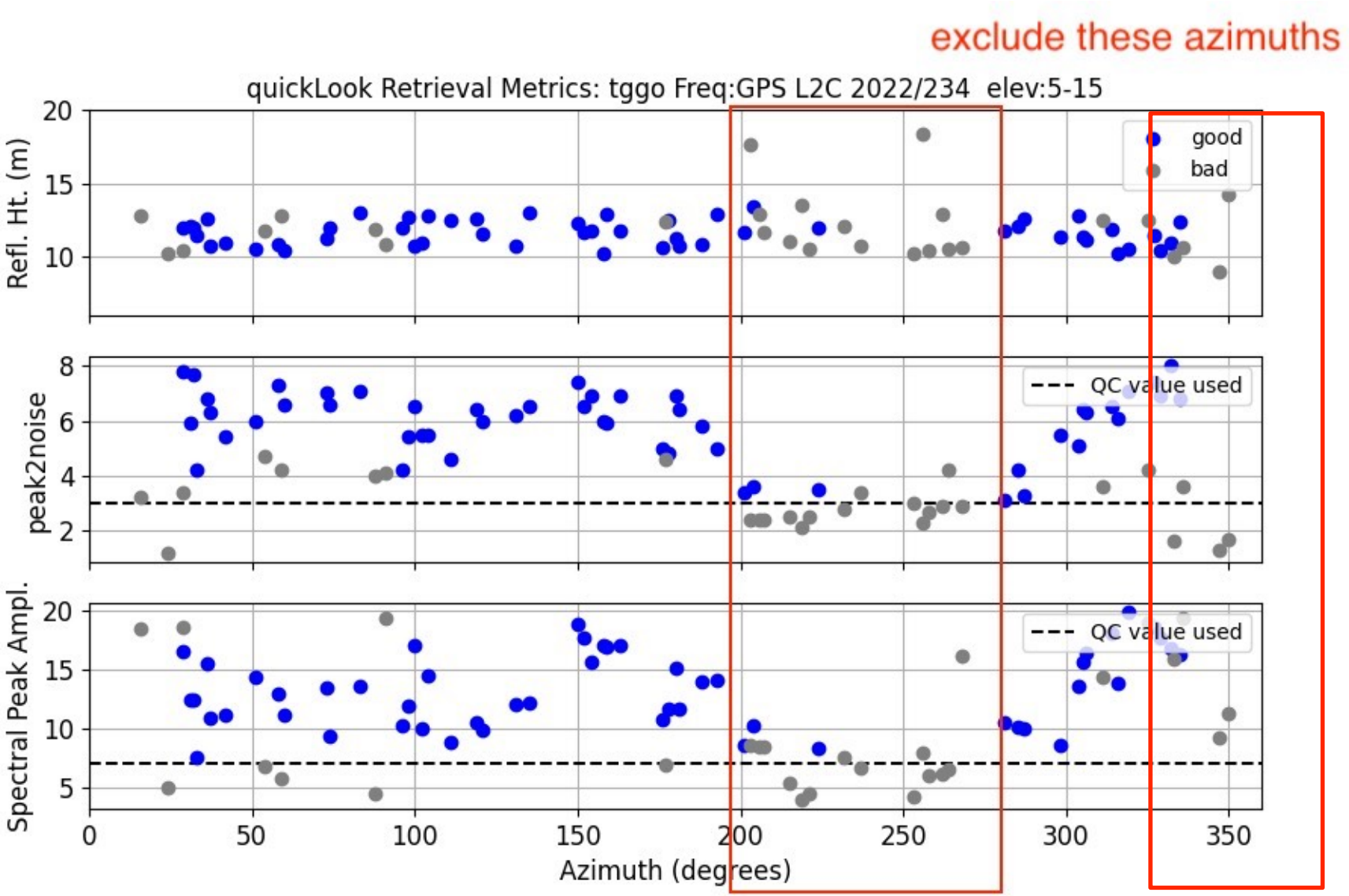
Why 15 seconds? 30 second data violate the maximum resolvable RH for L1 signals



```
quickLook tggo 2022 234 -fr 20 -e1 5 -e2 15 -h1 6 -h2 20
```

The first plot shows periodograms in the four geographic coordinates.




exclude these azimuths
quickLook Retrieval Metrics: tggo Freq:GPS L2C 2022/234 elev:5-15
Refl. Ht. (m)
good
bad
peak2noise
QC value used
Spectral Peak Ampl.
QC value used
Azimuth (degrees)

Set your analysis strategy (I am leaving out Galileo)

```
gnssir_input tggo  -h1 6 -h2 20 -e1 5 -e2 15 -h1 6 -h2 18
-allfreq 1 20 5 101 102 peak2noise 3.5 -azlist 30 180 270 330
-delTmax 40
```

Estimate RH

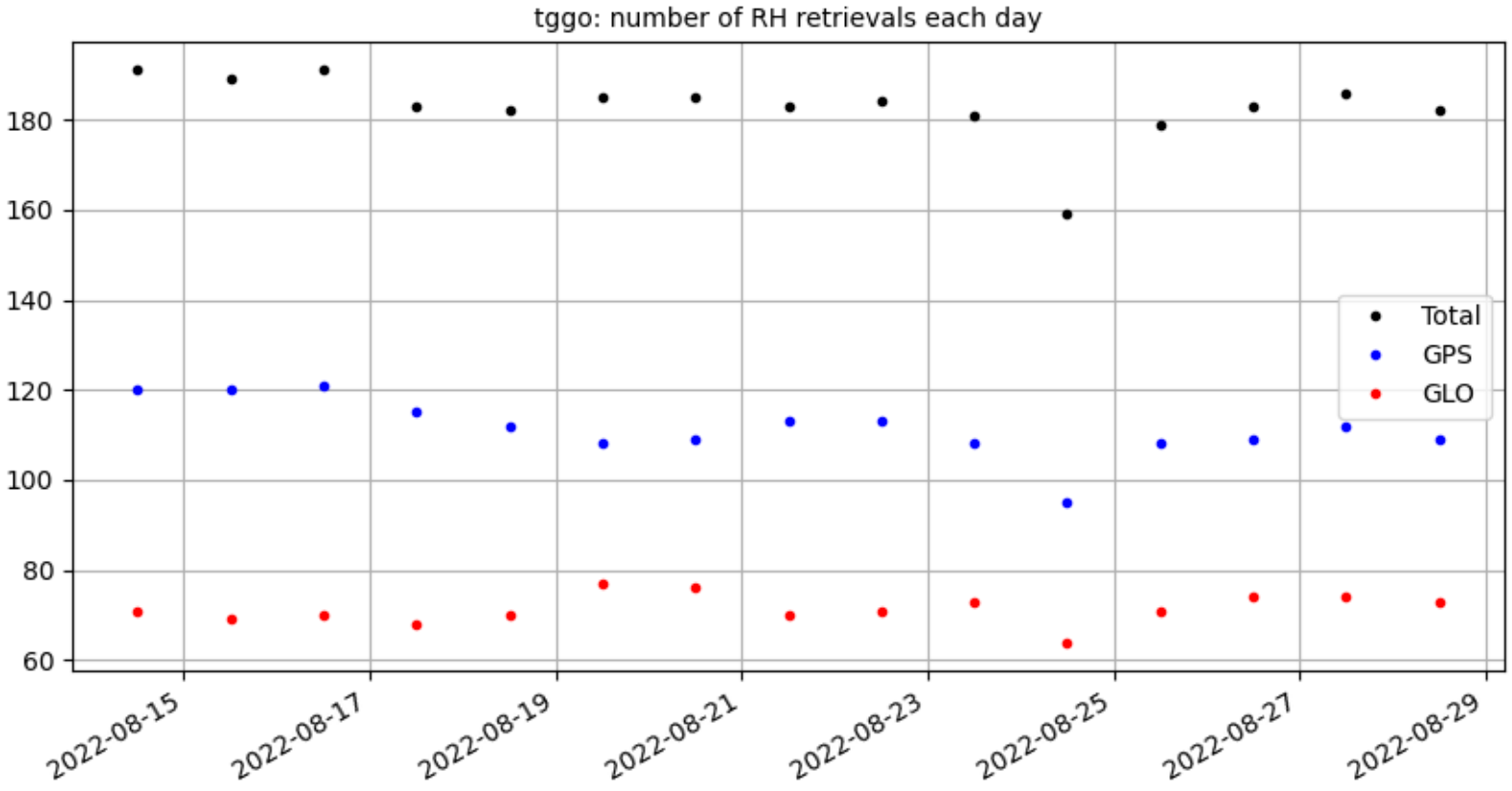
```
gnssir tggo 2022 226 -doy_end 240
```

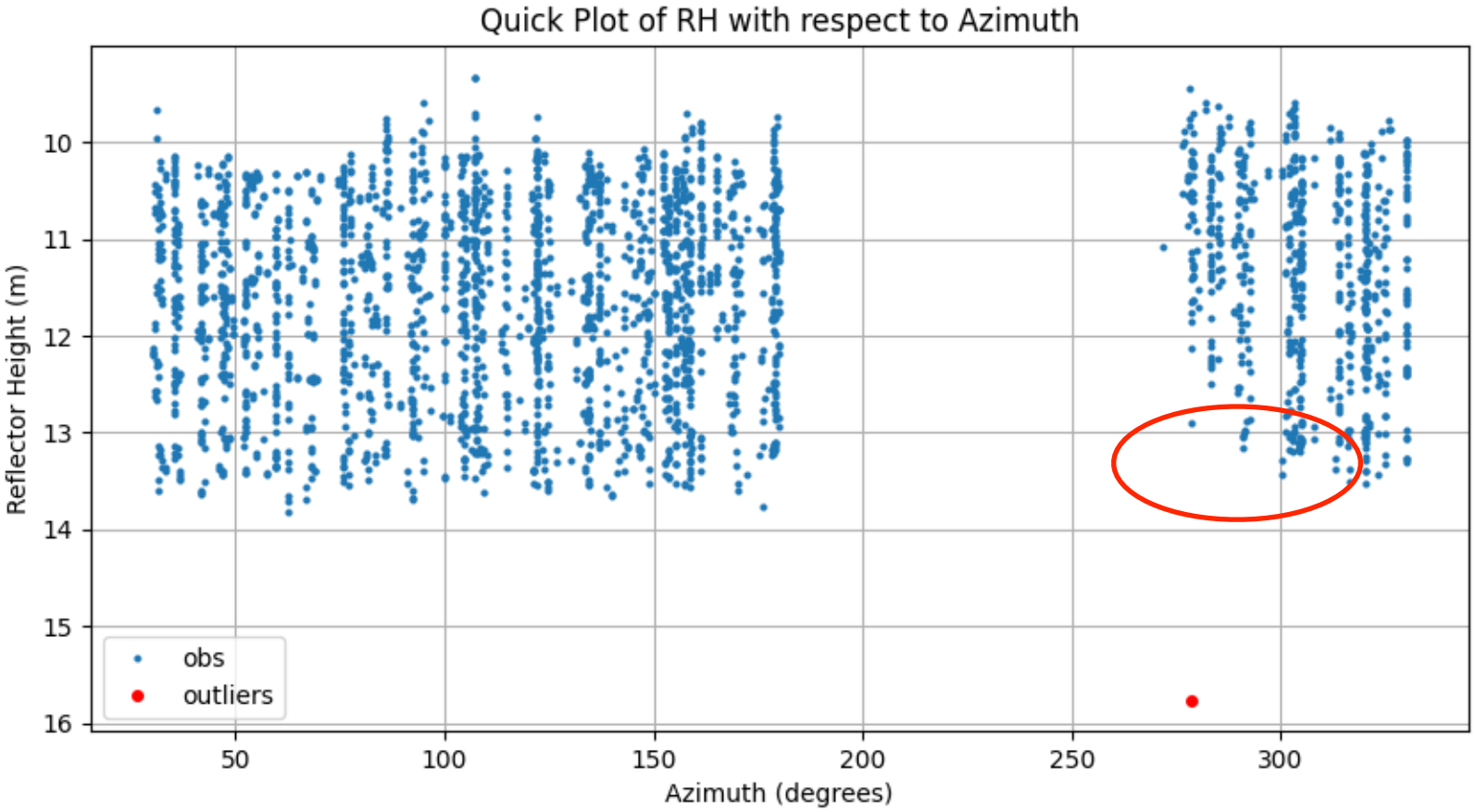
Look at the results - look for things you might need to change

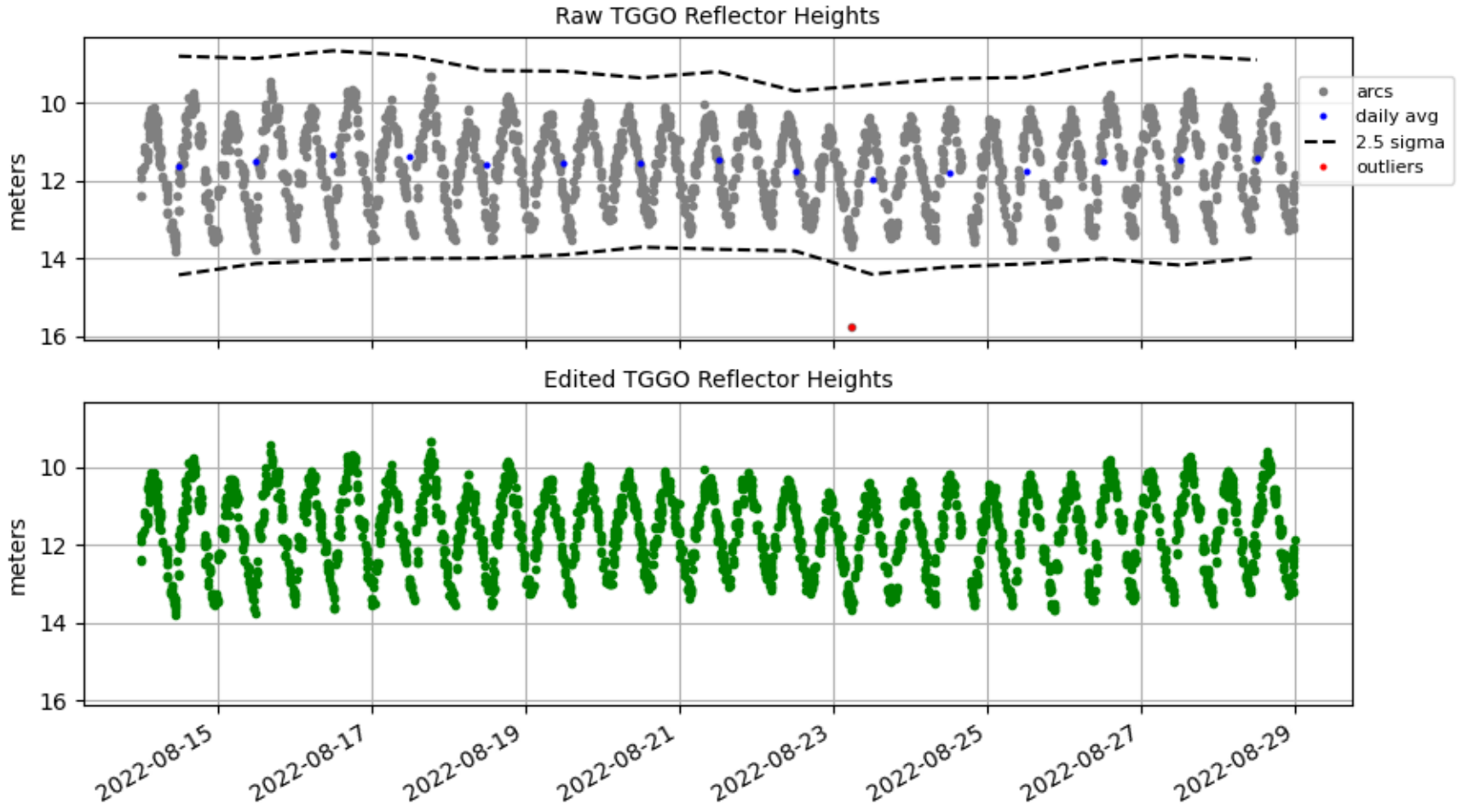
```
subdaily tggo 2022
```

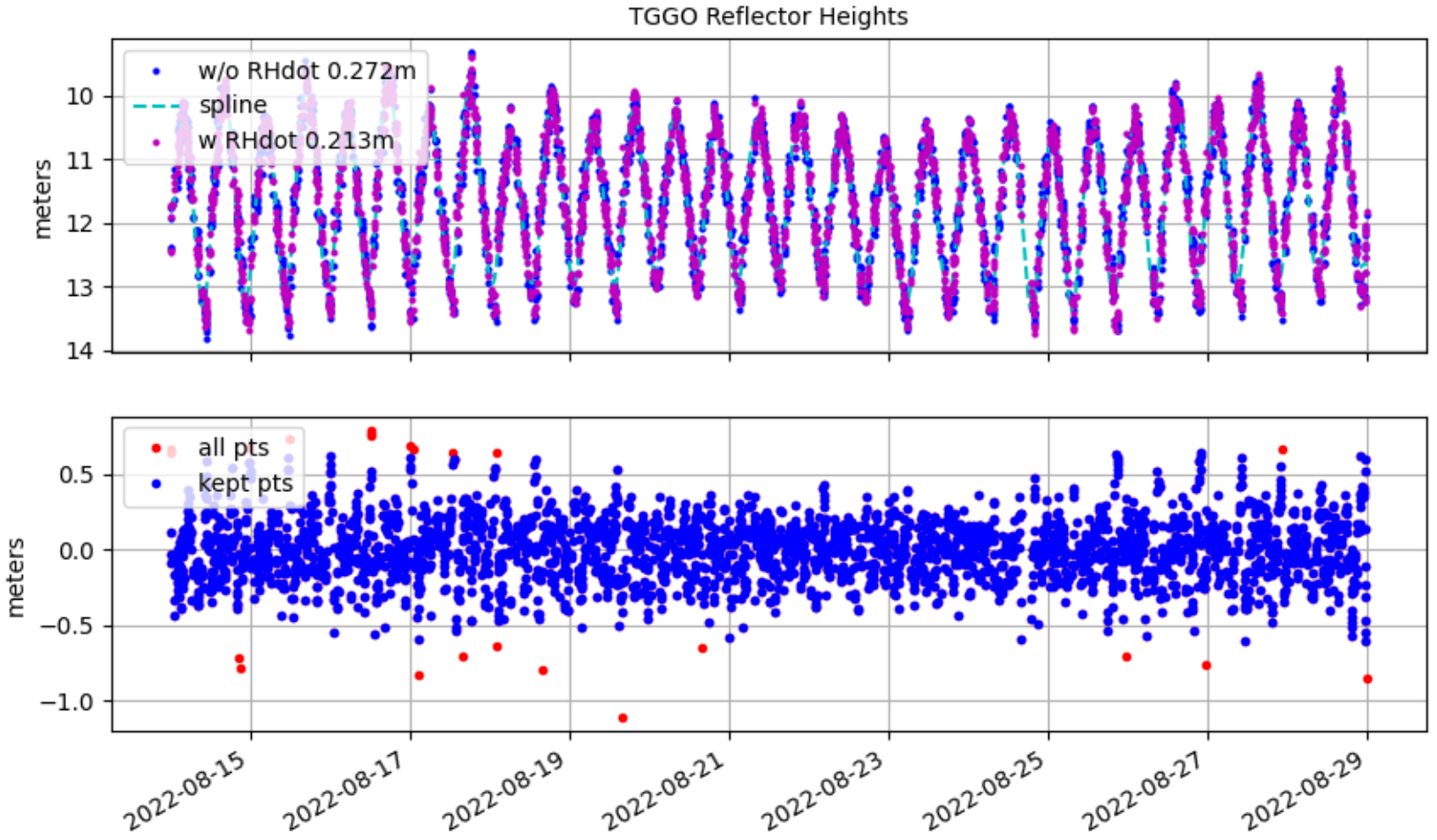
Iterate if necessary

I will likely be changing the gnss_input module to have a "water" vs snow/soil option so you don't have to set delTmax

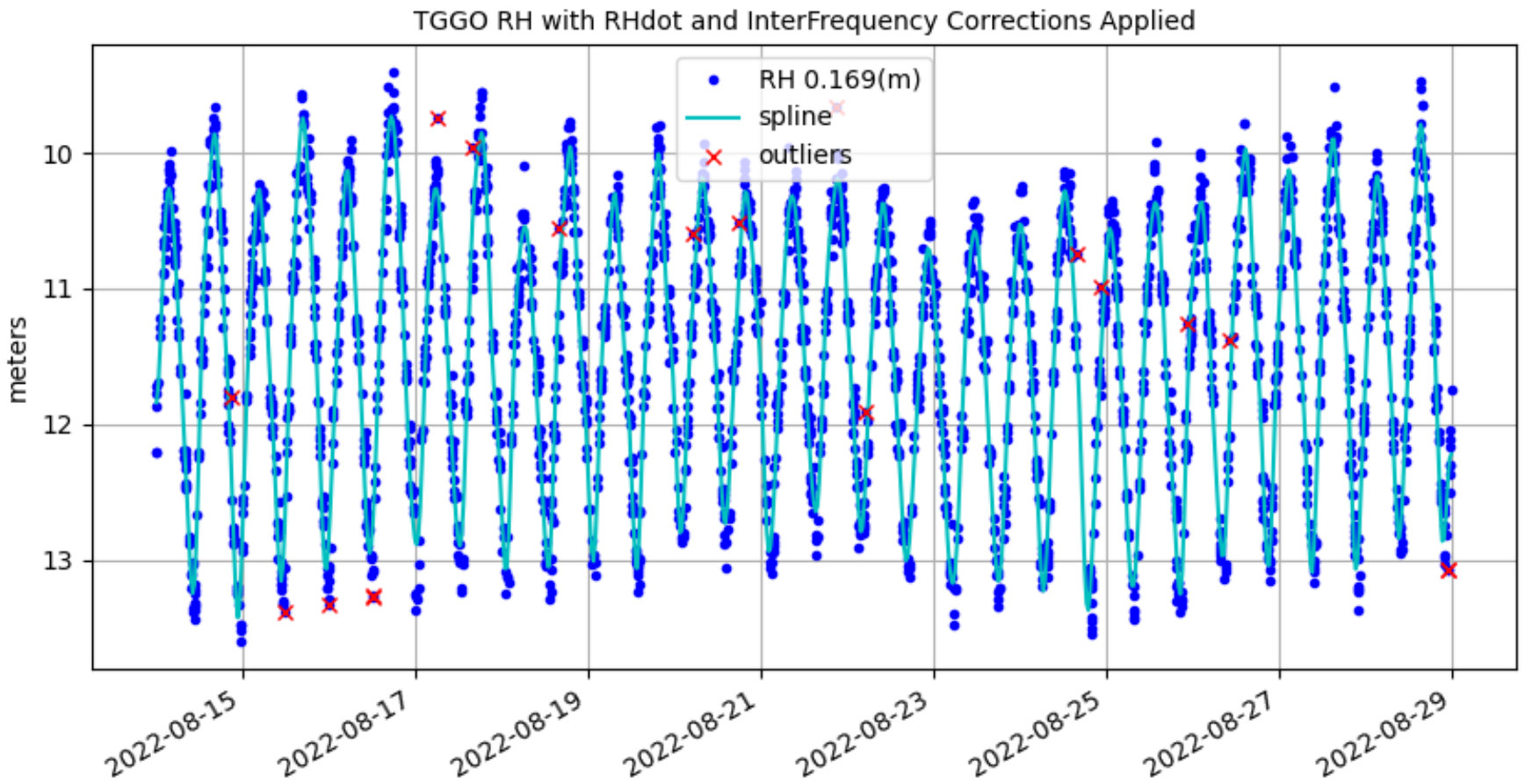

tggo: number of RH retrievals each day
180
160
140
120
100
80
60
2022-08-15
2022-08-17
2022-08-19
2022-08-21
2022-08-23
2022-08-25
2022-08-27
2022-08-29
Total
GPS
GLO


Quick Plot of RH with respect to Azimuth
Reflector Height (m)
10
11
12
13
14
15
16
50
100
150
200
250
300
Azimuth (degrees)
obs
outliers

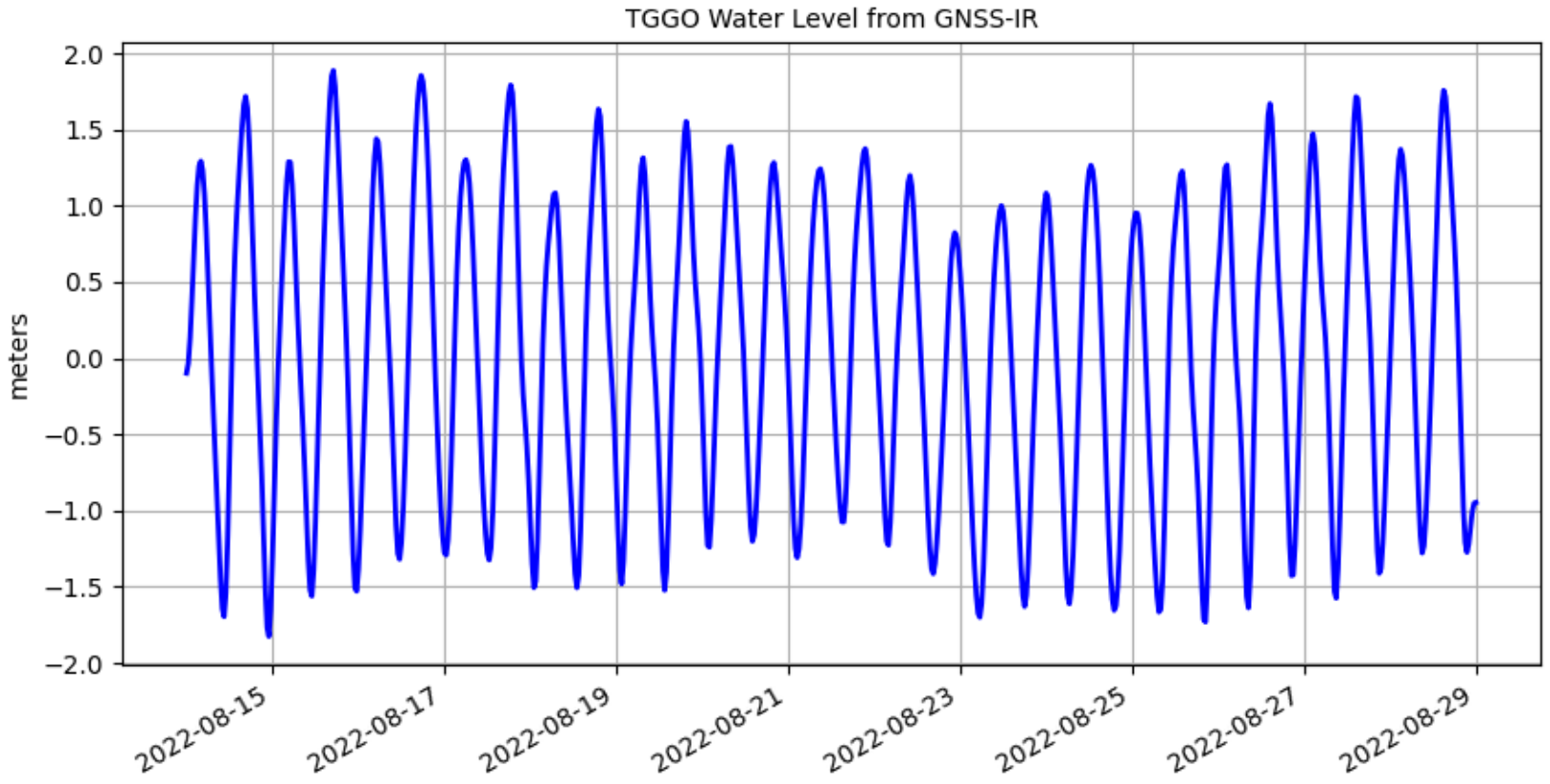

Raw TGGO Reflector Heights
meters
10
12
14
16
arcs
daily avg
2.5 sigma
outliers
Edited TGGO Reflector Heights
meters
10
12
14
16
2022-08-15
2022-08-17
2022-08-19
2022-08-21
2022-08-23
2022-08-25
2022-08-27
2022-08-29

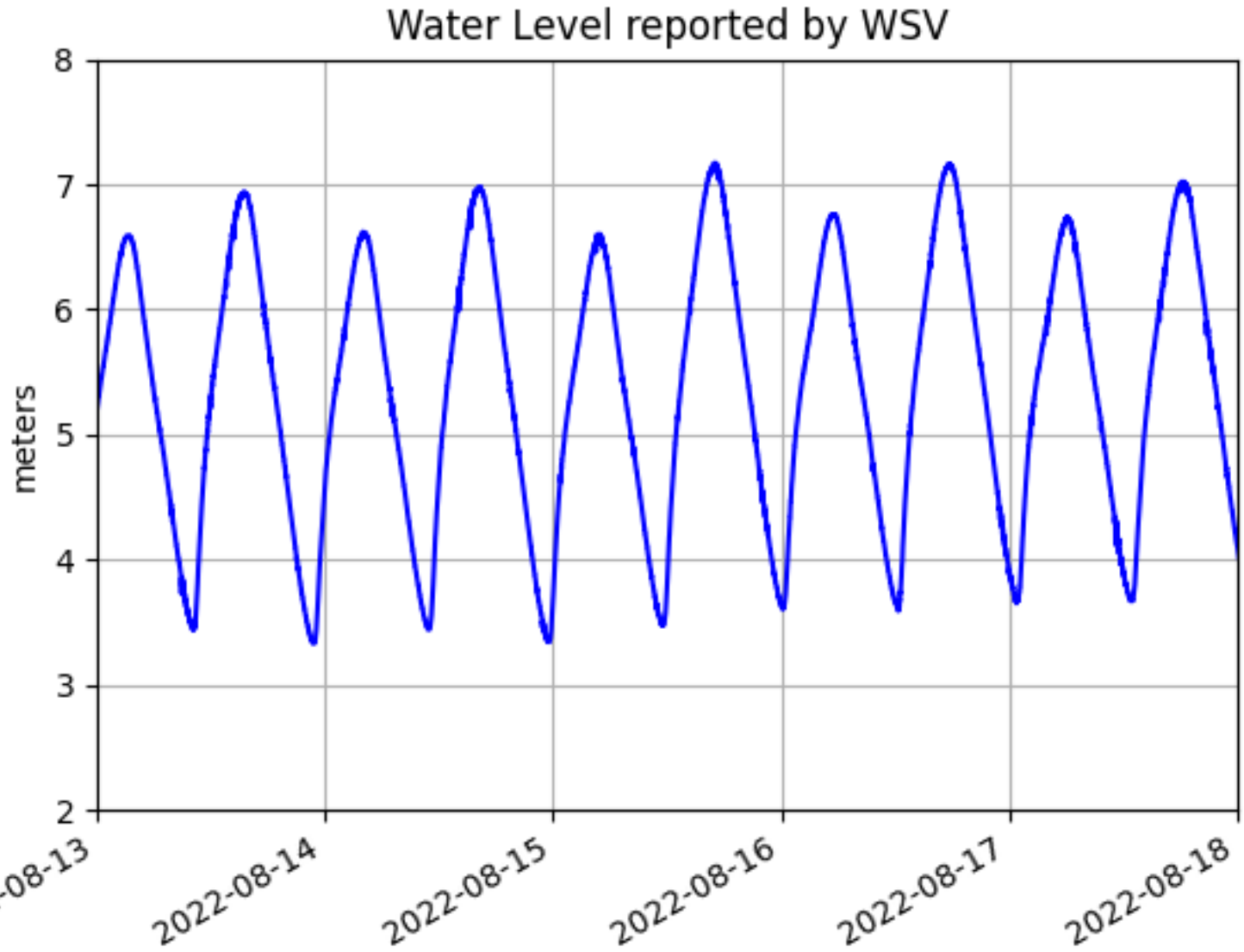

TGGO Reflector Heights
w/o RHdot 0.272m
spline
w RHdot 0.213m
meters
10
11
12
13
14
all pts
kept pts
meters
0.5
0.0
−0.5
−1.0
2022-08-15
2022-08-17
2022-08-19
2022-08-21
2022-08-23
2022-08-25
2022-08-27
2022-08-29

Final GNSS-IR result



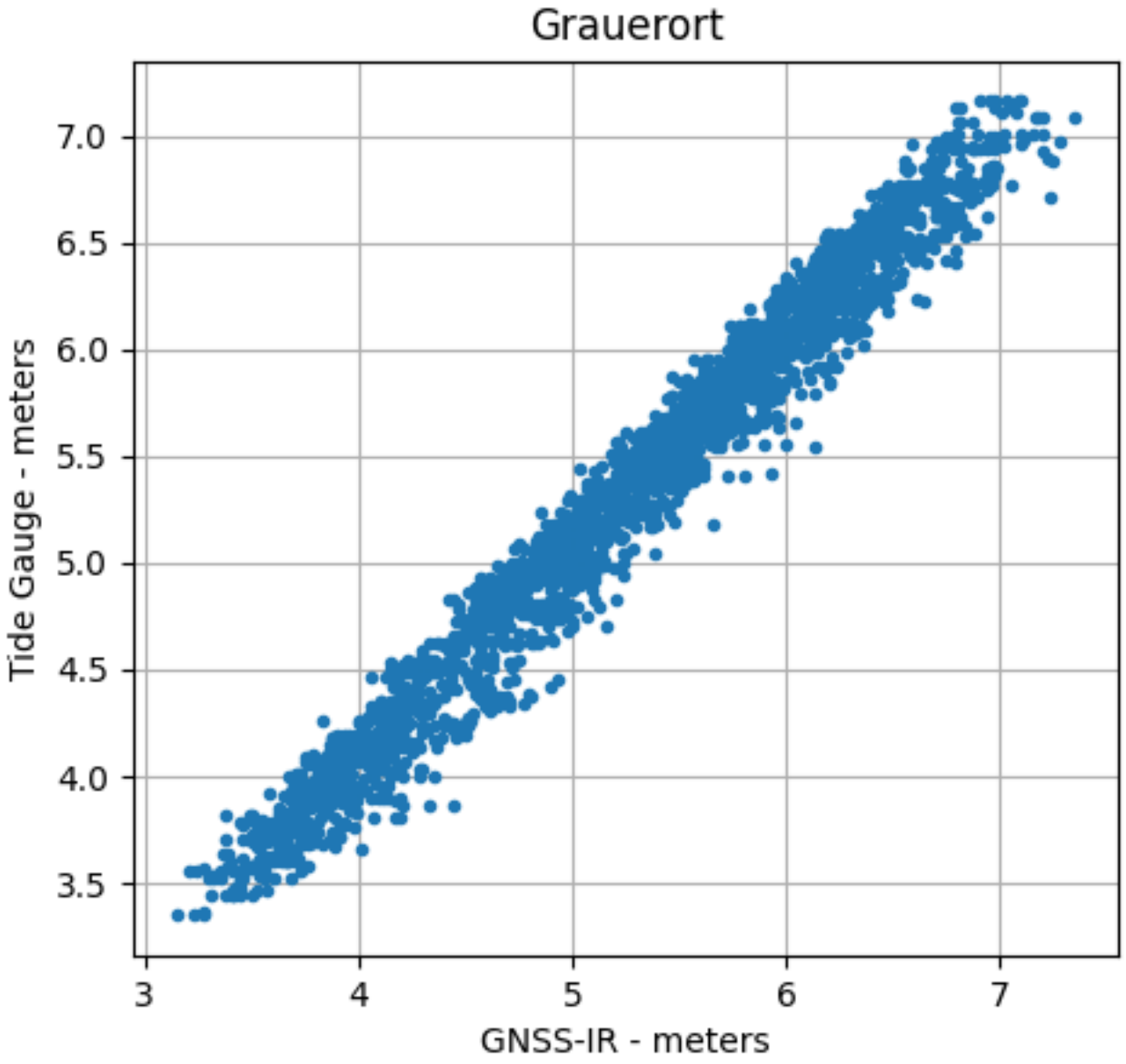
orthometric defined/final spline fit - user defined interval





Water levels on this river have very sharp changes at the max and min. Difficult to model Hdot. In this case, the RMS from the truth is actually better than the RMS from the spline.

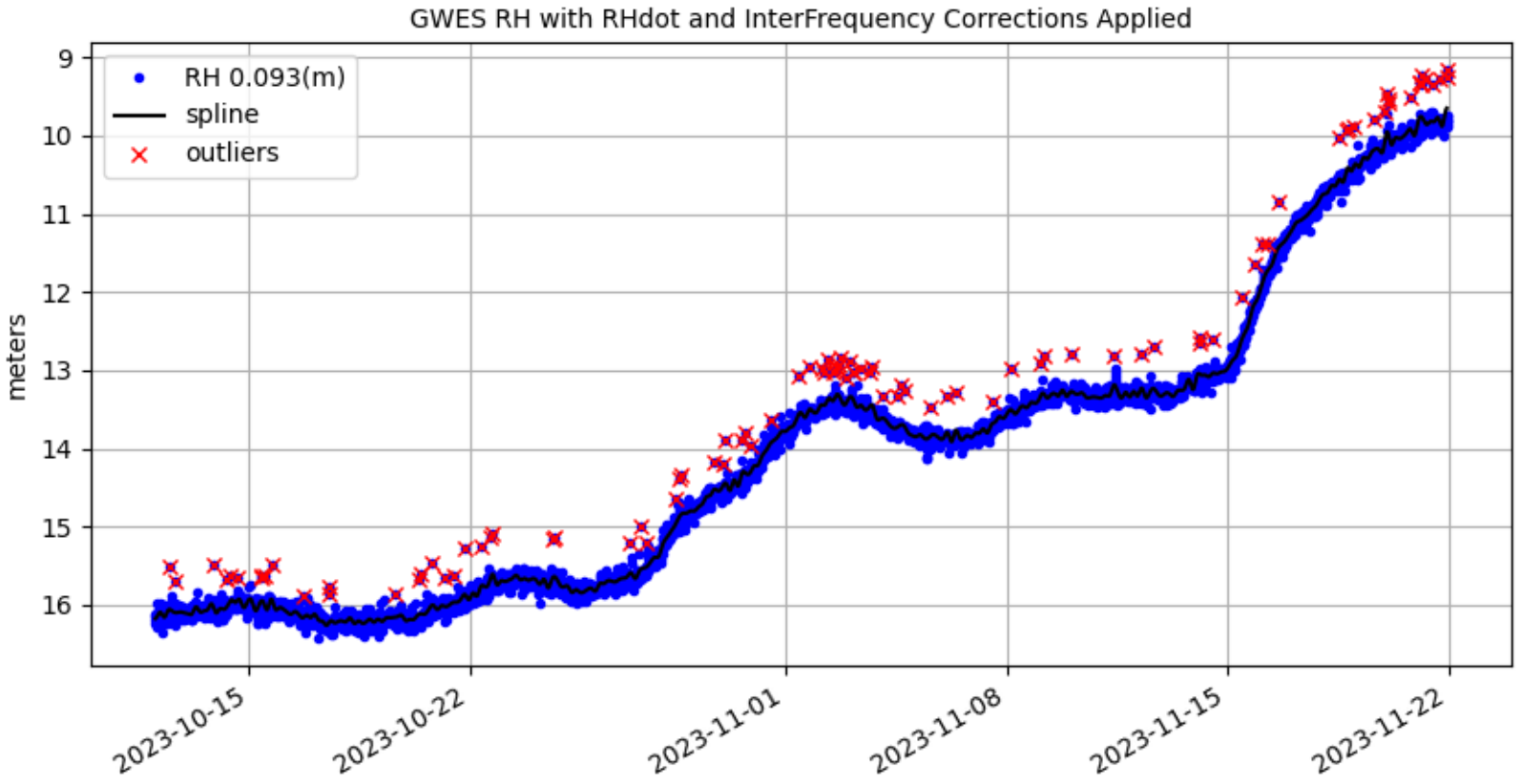
We still have good correlation (0.98), but there are still ways, in my opinion, that GNSS-IR can be improved at this site.



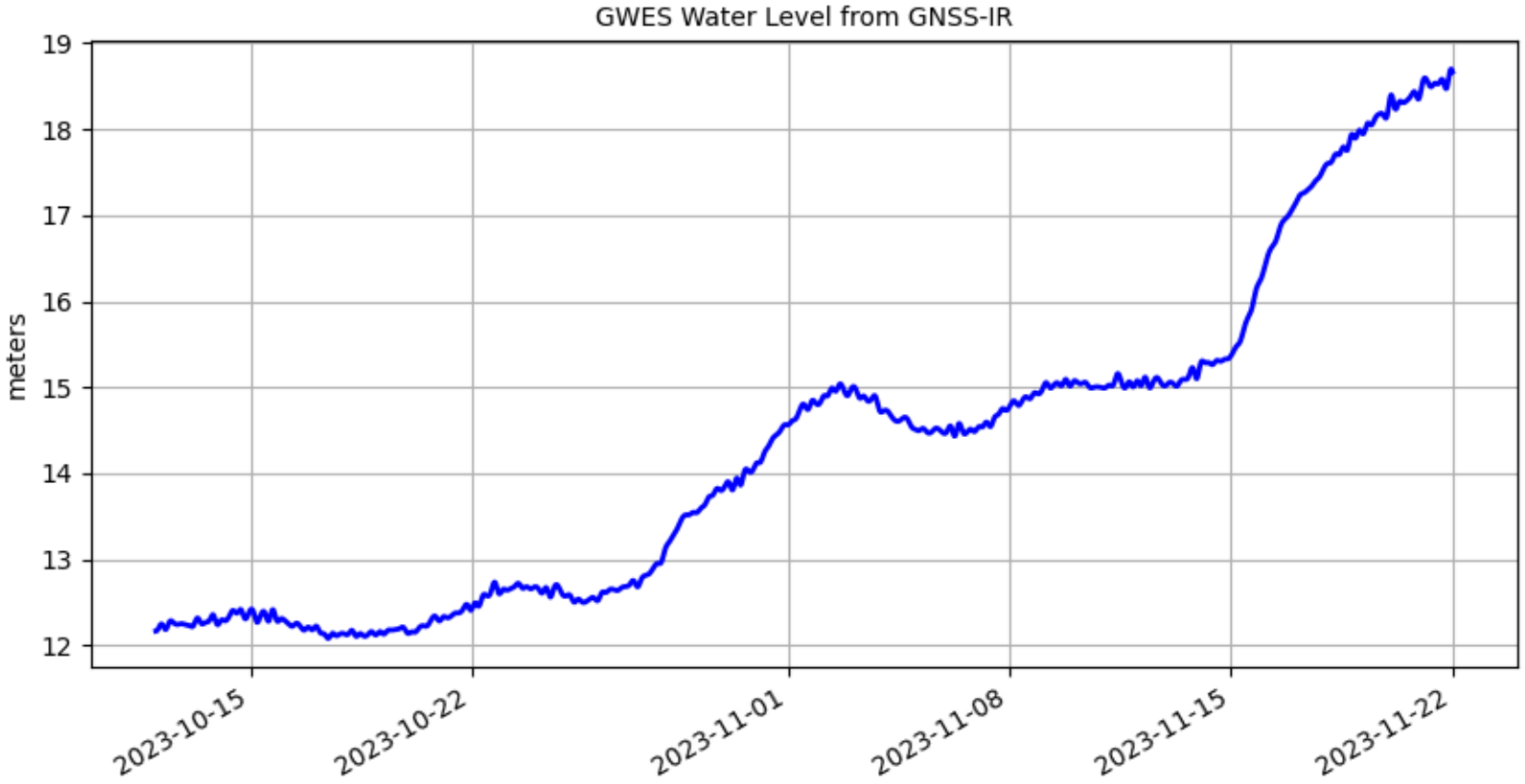
back to GWES (Wesel)

- It is on the Rhine, so 99% of the time you can use *daily_avg*.
- But what about when the river level is rapidly changing ? Remember that gap?
- You can use *subdaily*, but you must use it smartly.
  - If you use defaults - which are meant for tidal regimes - you will overfit the data. You need to change -knots
  - But *subdaily* does have better information for understanding your outliers.

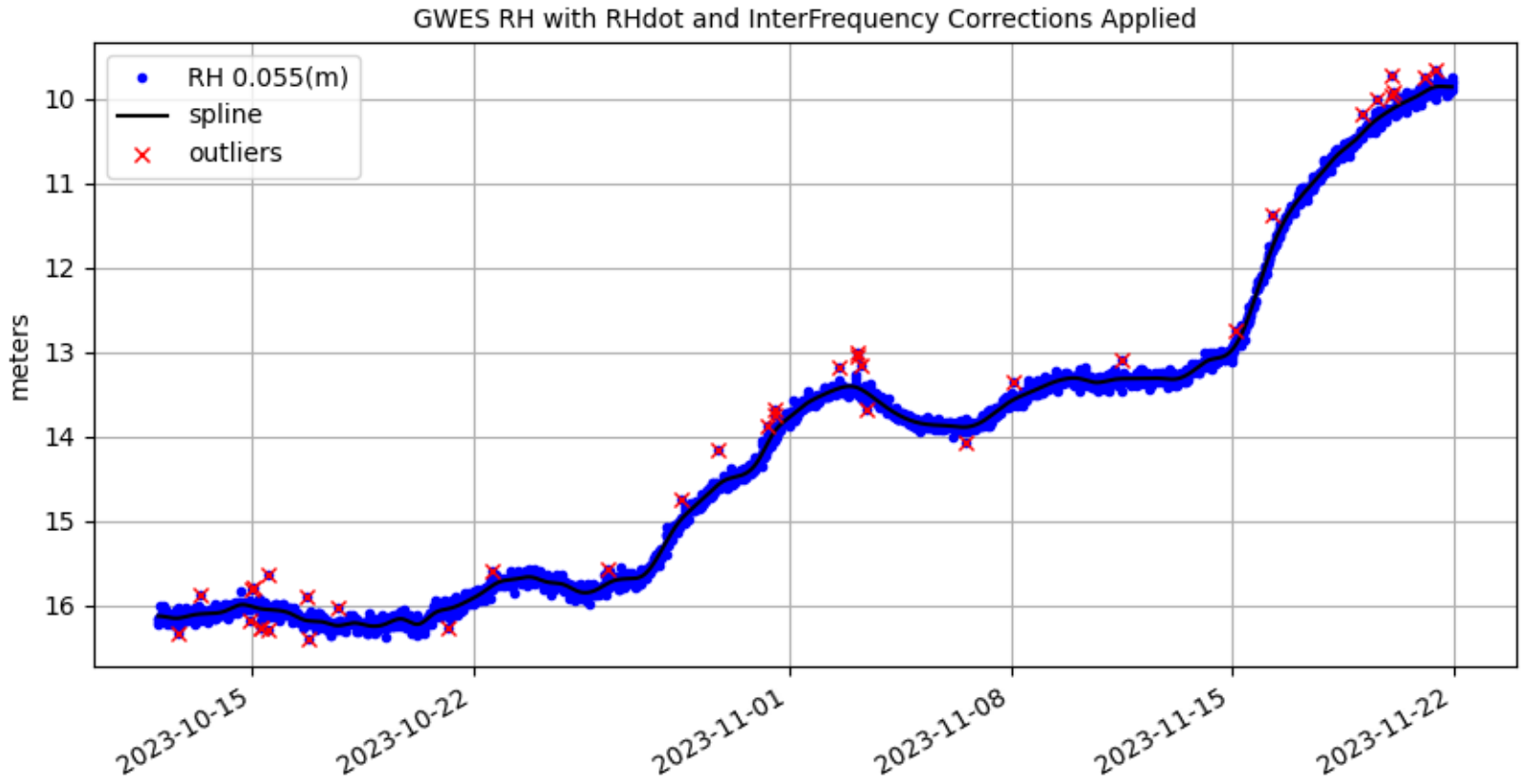
Using *subdaily* with defaults - pretty clear that my reflection mask was not perfect

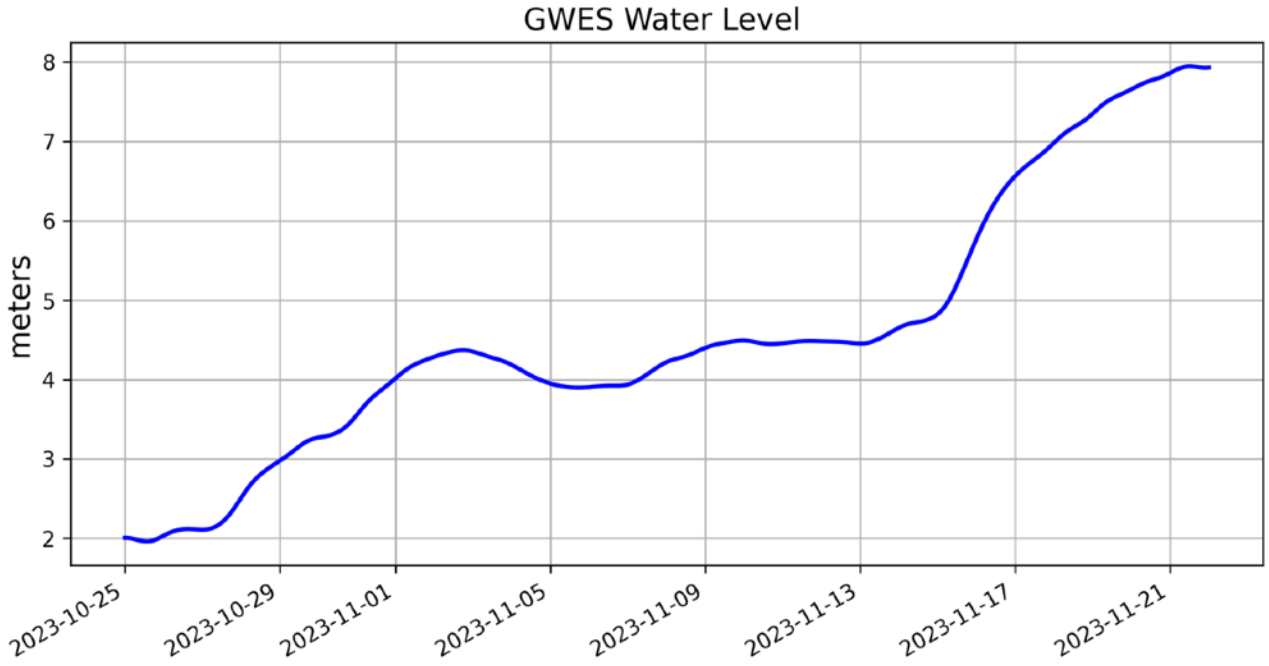


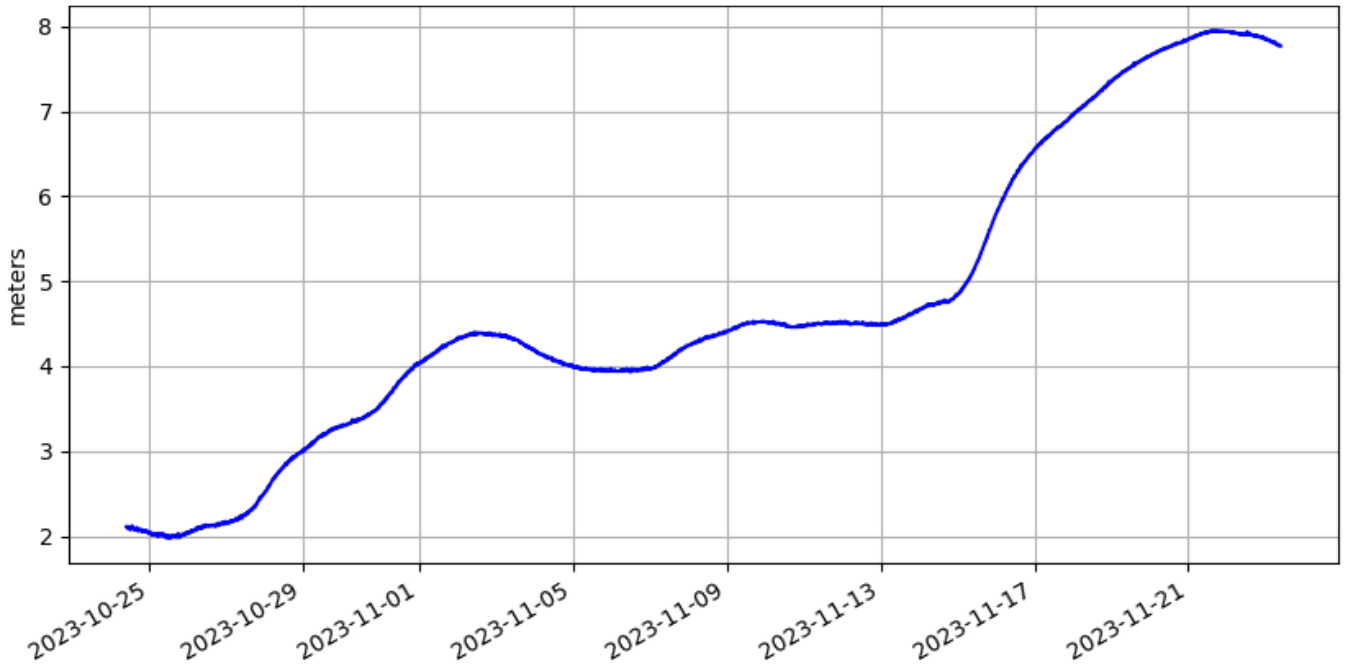
And now I am clearly overfitting (the default is a knot every three hours)



Made changes to strategy (i.e. I reran *gnssir_input* and *gnssir*). Very fast now that the SNR files exist.







One of these is the official German tide gauge record and one is GNSS-IR.

To be honest, daily averages are probably still good enough for most people