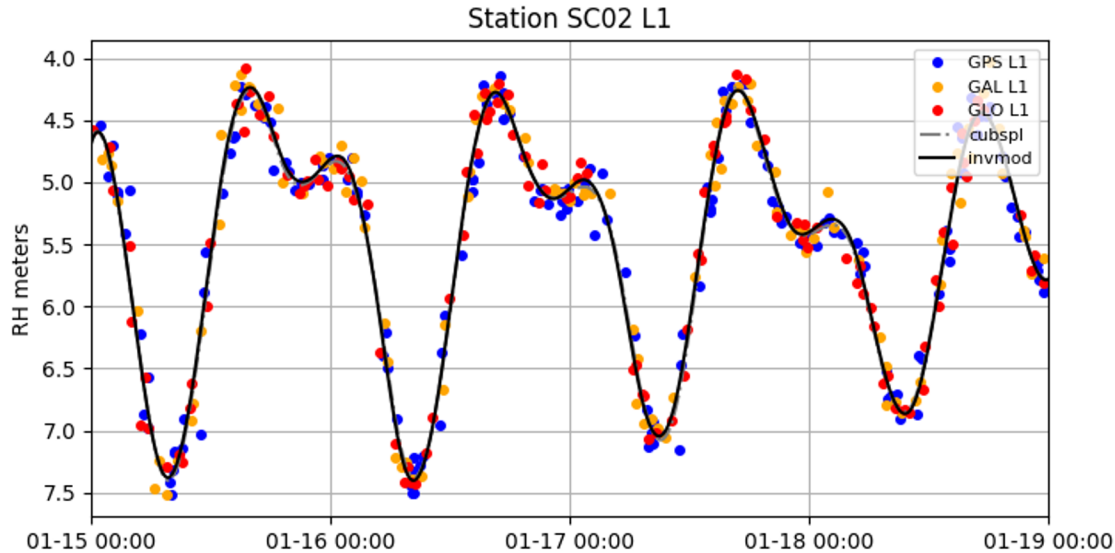


# 2024 GNSS-IR short course: 'invsnr'



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# What is 'invsnr'?

'invsnr' is a physics-informed way of obtaining a smoothly varying reflector height / water level time series at regular intervals

Why is it useful?

- Water levels tend to vary smoothly
- Satellite passes are randomly distributed in time
- Difficult to interpret data points from the same time with different values
- Smoothing reduces the effect of random noise in spectral analysis

When is it useful?

- If you care about sub-daily reflector heights e.g., tides, flooding
- If your signal is smaller or similar magnitude to random noise in measurements

# History of 'invsnr'

 AGU PUBLICATIONS



## Radio Science

### RESEARCH ARTICLE

10.1002/2016RS006057

#### Key Points:

- We present an advanced method for retrieving sea surface heights using

## Improving GNSS-R sea level determination through inverse modeling of SNR data

Joakim Strandberg<sup>1</sup>, Thomas Hobiger<sup>1</sup>, and Rüdiger Haas<sup>1</sup>

## Quantifying the Uncertainty in Ground-Based GNSS-Reflectometry Sea Level Measurements

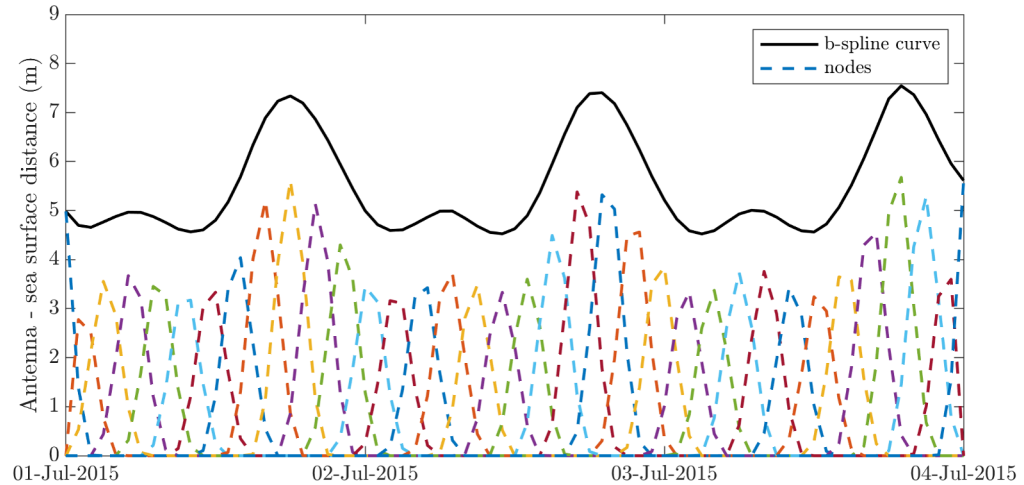
David Purnell<sup>1</sup>, Natalya Gomez<sup>1</sup>, Ngai Ham Chan<sup>1</sup>, Joakim Strandberg<sup>1</sup>, David M. Holland<sup>1</sup>, and Thomas Hobiger<sup>1</sup>

## Precise water level measurements using low-cost GNSS antenna arrays

David J. Purnell<sup>1</sup>, Natalya Gomez<sup>1</sup>, William Minarik<sup>1</sup>, David Porter<sup>2</sup>, and Gregory Langston<sup>1</sup>

# From Strandberg et al. (2016)

- Reflector heights (Water levels) are modeled using a b-spline curve
- The curve is defined by node values with e.g., 12 nodes per 24hr
- Water level measurements can be taken at any time on the curve

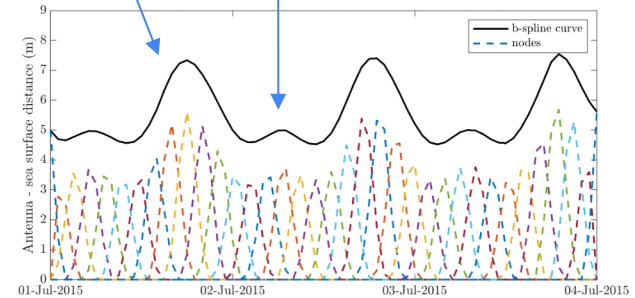
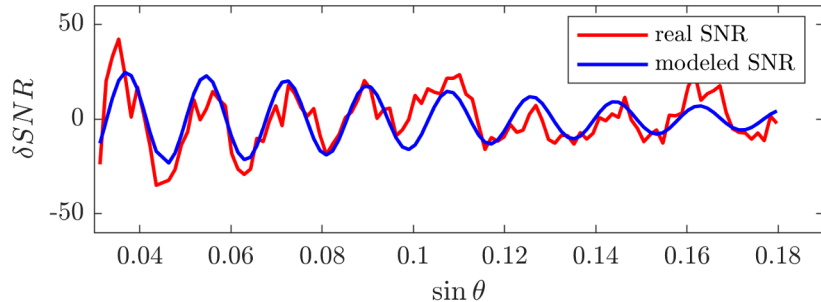


# From Strandberg et al. (2016)

- SNR data is modeled using:
- Inverse method: if real and modeled SNR match, then reflector height model should be good

$$\delta\text{SNR} = \left( C_1 \sin\left(\frac{4\pi h}{\lambda} x\right) + C_2 \cos\left(\frac{4\pi h}{\lambda} x\right) \right) e^{-4k^2 \Lambda x^2}$$

related to antenna gain pattern, surface roughness...



# Improvements

- Node values are first estimated using spectral analysis reflector height estimates (including 'rhdot' correction)
- Simplified spline curve:
  - Regularly spaced nodes (points along curve)
  - Cubic spline interpolation between points

Dominant peak  
from spectral  
analysis

dh/dt taken from  
curve

$$f = \frac{2}{\lambda} \left[ h + \frac{\partial h}{\partial t} \frac{\tan \theta}{\partial \theta / \partial t} \right]$$

KL: With Dave's help, I ported invsnr into gnssrefl 2022. Added multi-frequency retrievals, more constellations, various orbits, refraction, etc. However, the QC is not identical to gnssir. If you want to use Lomb Scargle periodograms, you should use gnssir. Here they are used as a comparison point. I also added the "risky" option.

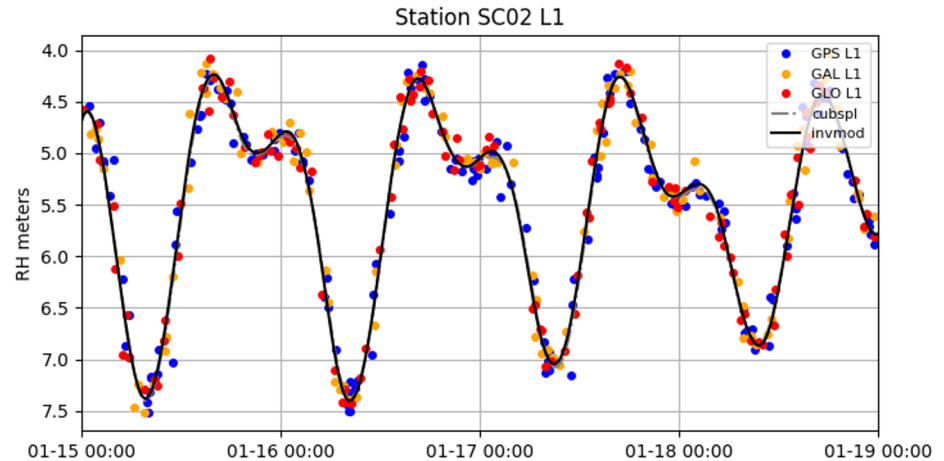
## Example: SC02, Friday Harbor, WA

```
rinex2snr sc02 2021 015 -orb gnss -doy_end 045
```

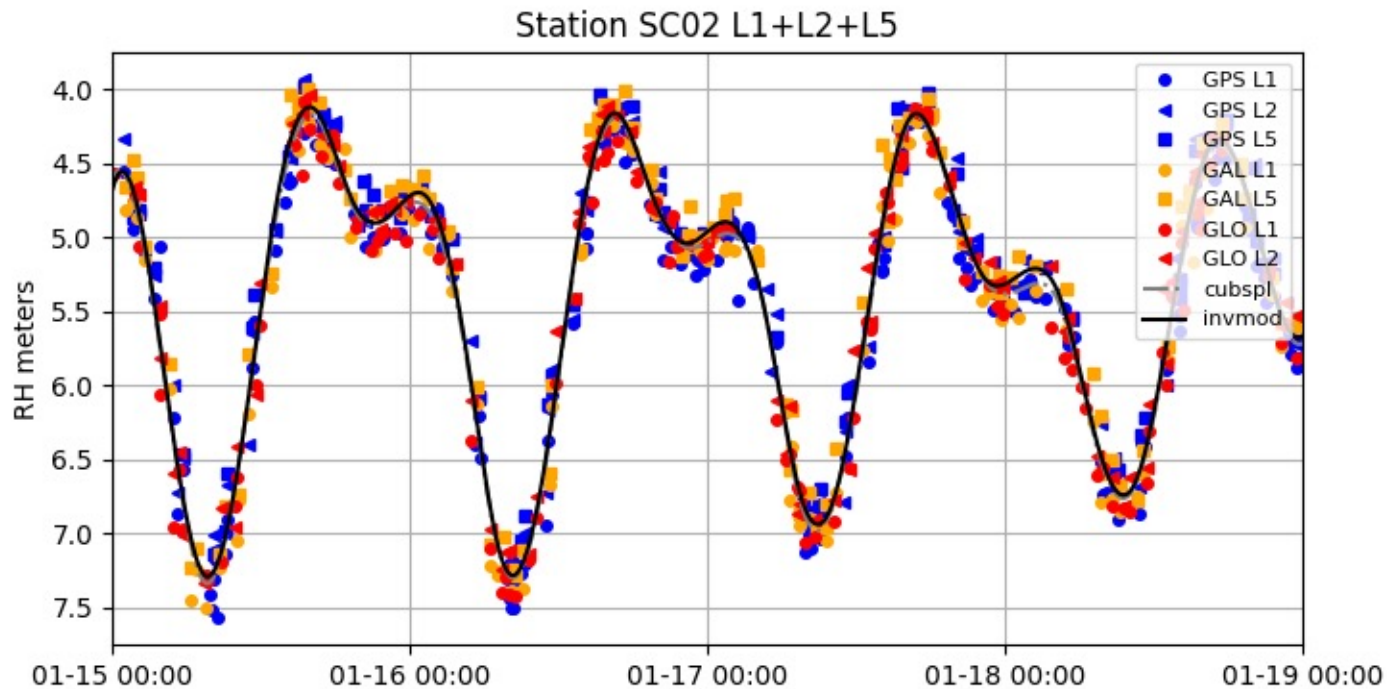
```
invsnr_input sc02 -h1 3 -h2 12 -e1 5 -e2 13 -azim1 60 -azim2 220
```

```
invsnr sc02 2021 15 L1 -doy_end 18 -pktnlim 3
```

- Azimuth, elevation angle and reflector height limits taken from literature
- More important to get multiple constellations than multiple frequencies, hence '-orb gnss' and 'L1'



L1+L2+L5 all good azimuths and three constellations

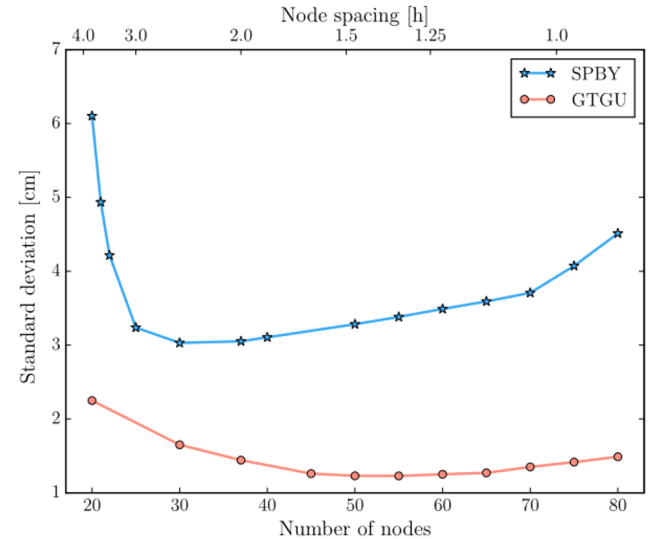




## Note on parameters: 'knot\_space' and 'risky'

- The time between nodes is set using 'knot\_space' (in hours)
- The more frequent the nodes, the more accurate water level representation is theoretically possible
- However, if there is a gap in the data bigger than the node spacing, there might be instabilities (unphysical height variations)

**Note: this is the same problem as 'overfitting' in machine learning**

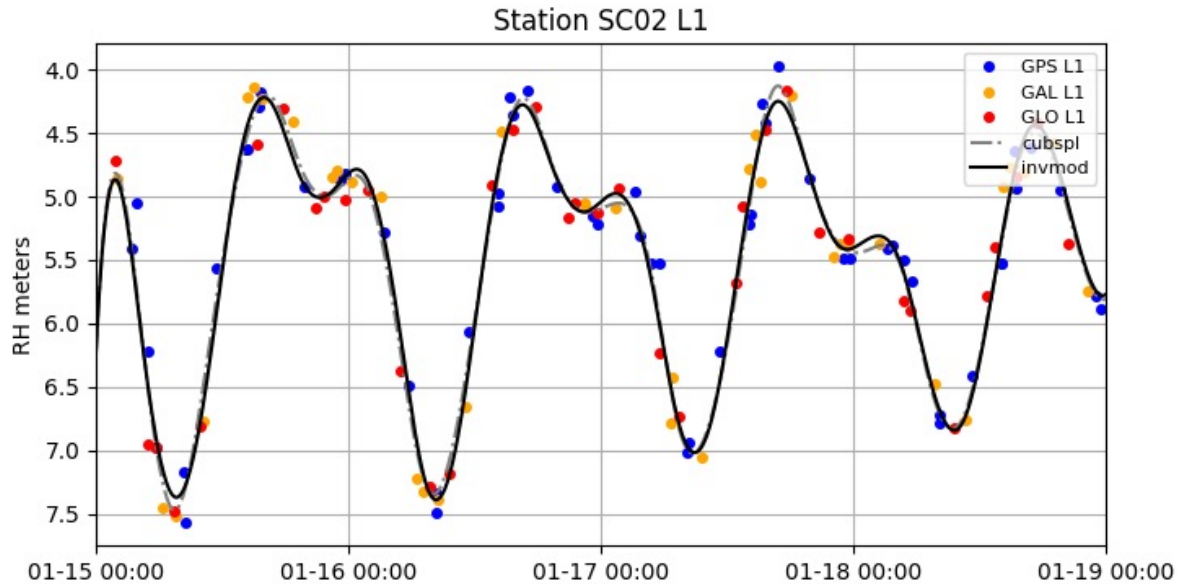


From Strandberg et al. (2016)

## Note on parameters: 'knot\_space' and 'risky'

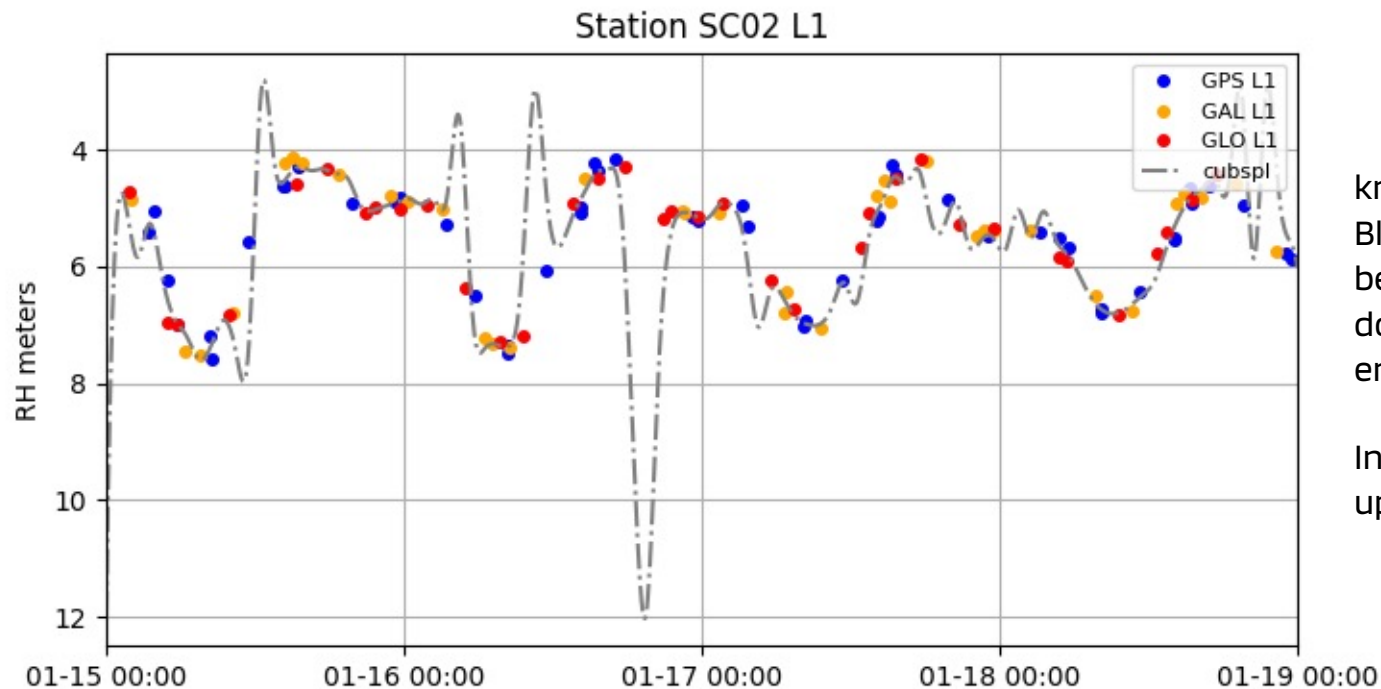
```
invsnr_input sc02 -h1 3 -h2 12 -e1 5 -e2 13 -azim1 60 -azim2 120
```

```
invsnr sc02 2021 015 L1 -doy_end 018 -pktnlm 3
```



Default  
knot\_space = 3  
Still OK

```
invsnr sc02 2021 015 L1 -doy_end 018 -pktnlim 3 -snrfit False -risky True -  
knot_space 1
```



knot\_space = 1  
Blows up  
because you  
don't have  
enough data

Invsnr also blows  
up.

# TGMX: Puerto Morelos

Personally, I do not like it when people put a GNSS antenna in such a cluttered environment.

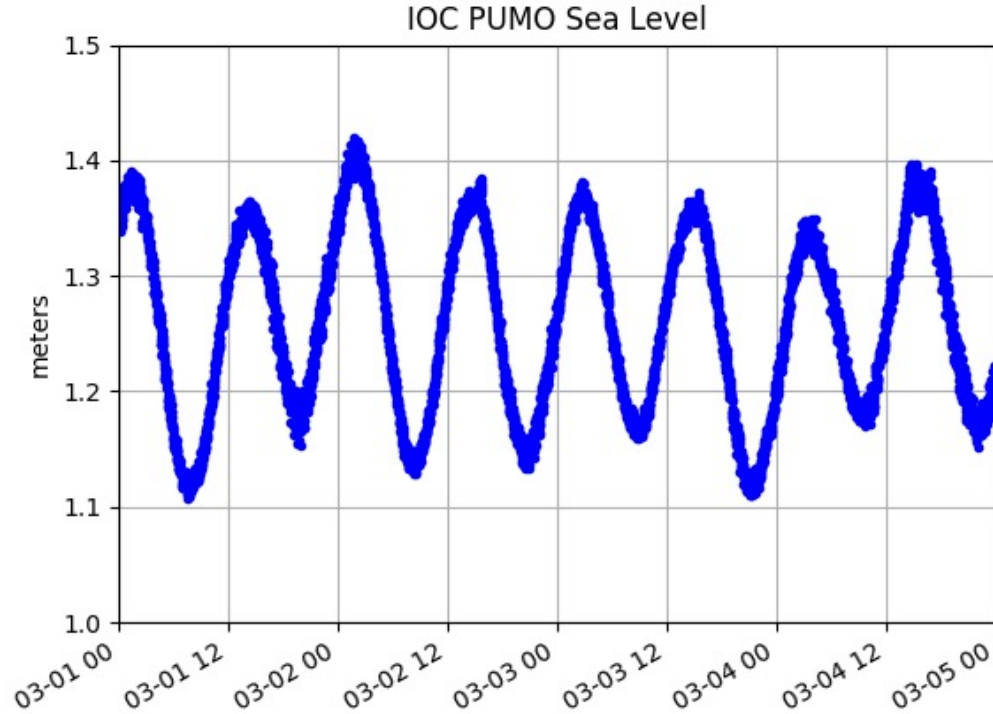
It has been listed as equipment failure since 2022.

Although on the ocean, some of the azimuths are not usable.

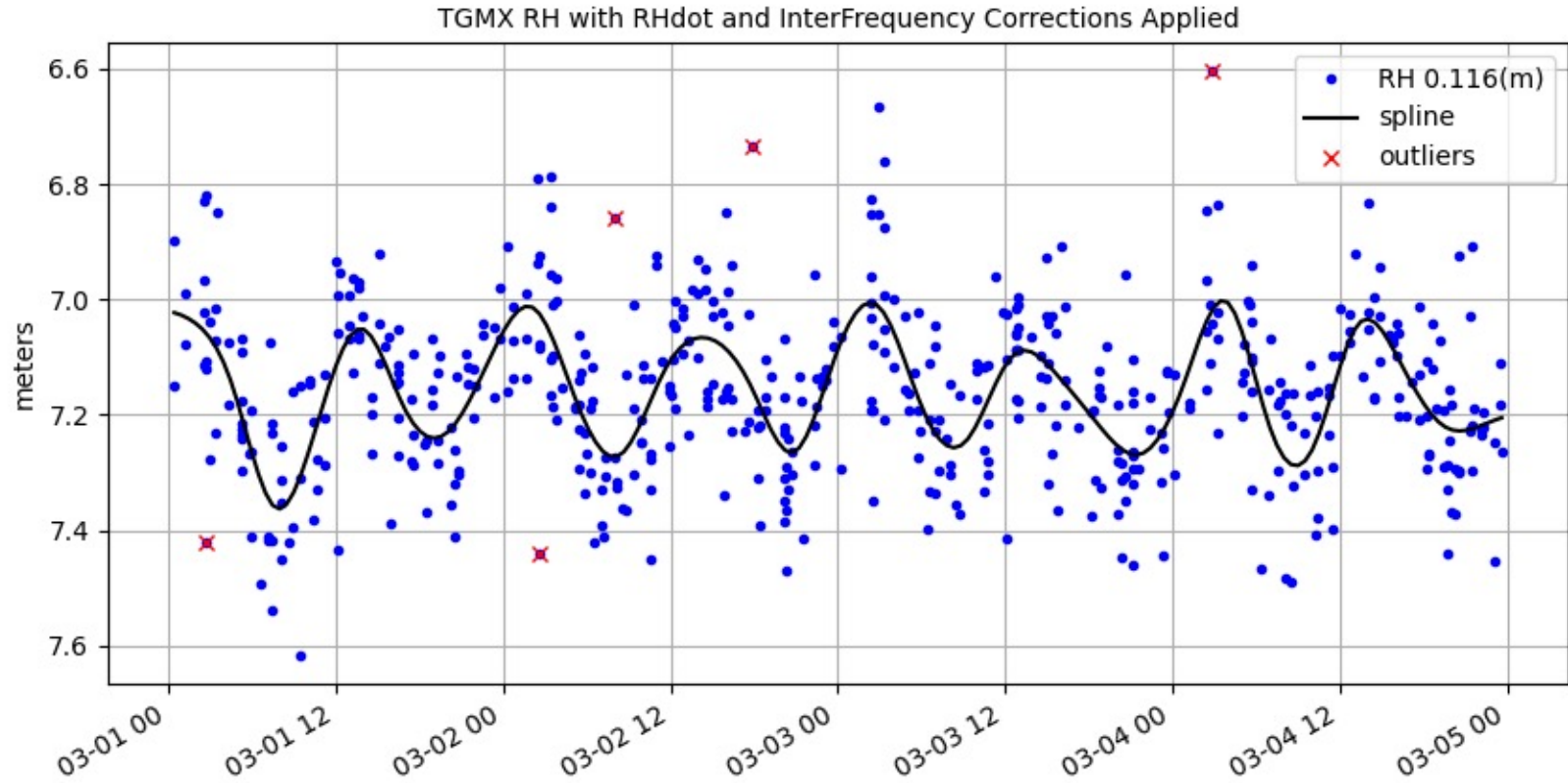
Reflected signals aren't going to be able to travel through those built/metal surfaces.



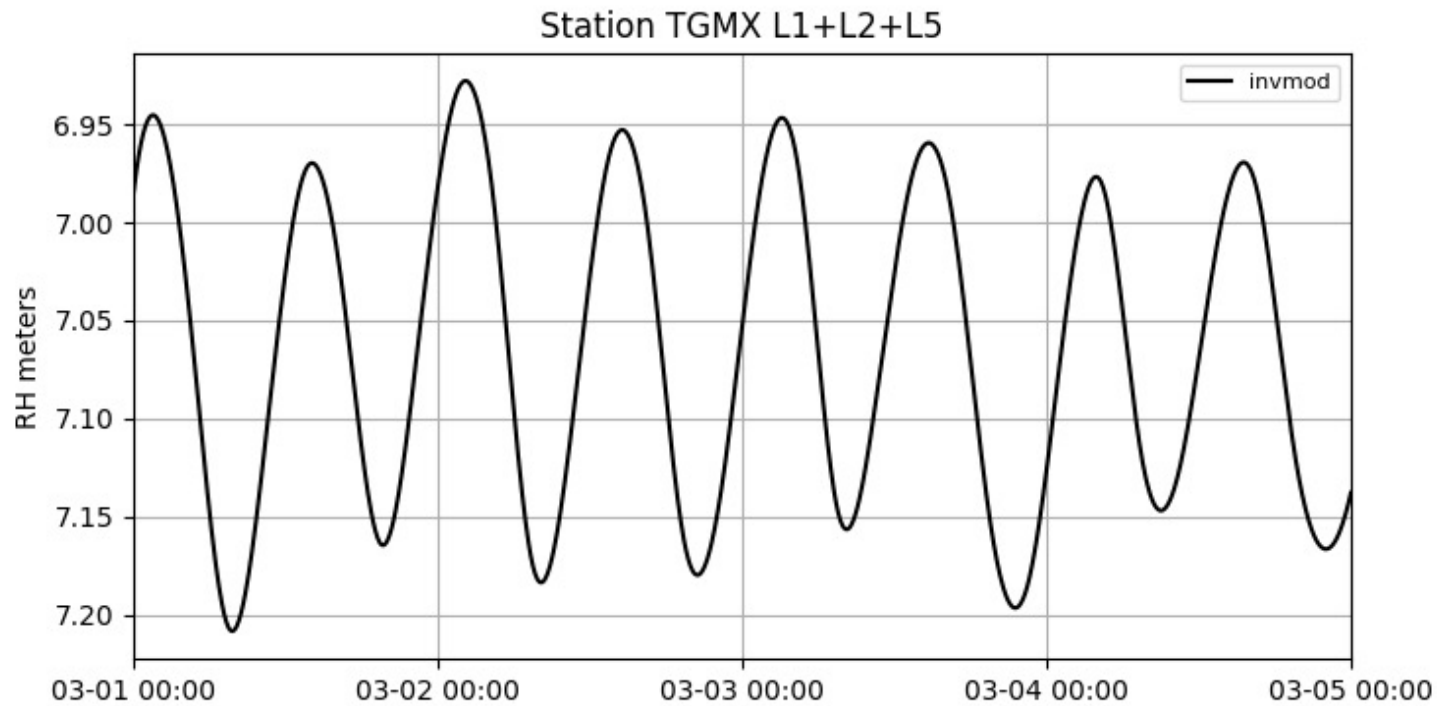
# Traditional tide gauge (IOC) – small tidal signal!

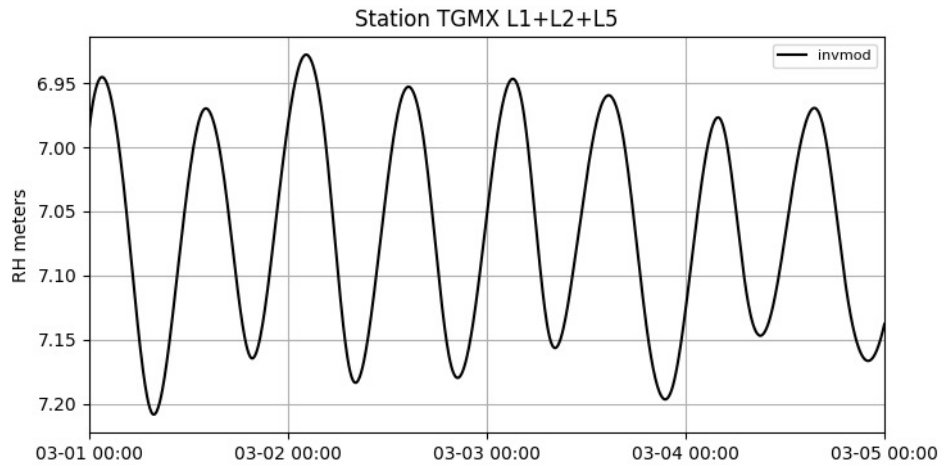


# Example 3: TGMX, Mexico using gnssir (and periodograms)

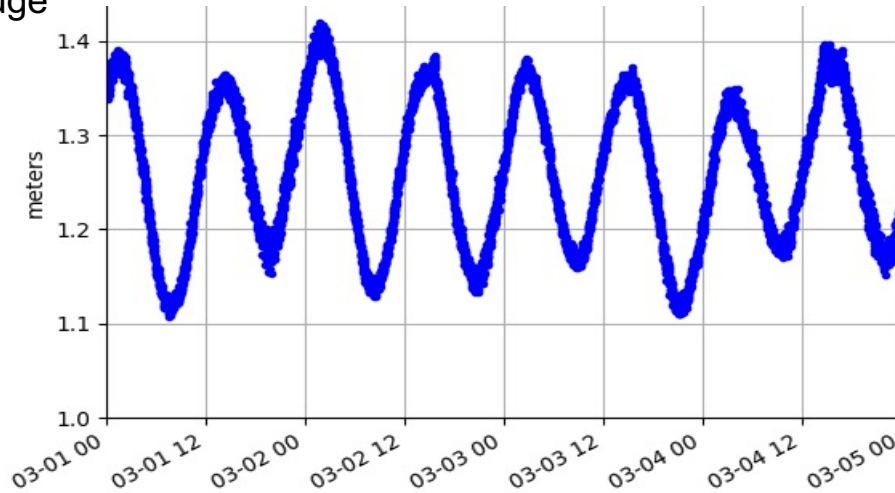


## Using invsnr -





invsnr and traditional tide gauge





# Comments

- Don't bother using 'invsnr' if the reflector heights don't look good to begin with!
  - Always start with 'quicklook' or refl zones web app
  - It is very important to have good azimuth and elevation angle masks
- If daily averages are good enough for your application, stick with that!
- If you are installing your own site and you want to use this technique the most important things are:
  - Wide view (azimuth) of surface
  - Multi-constellation data (just GPS is probably not good enough)
- Changing the input value 'roughness' might improve efficiency
- Really really slow if you use high-rate data.
- What to do about day boundaries?

If you want to improve the code:

- We could improve QC options on the periodogram side.
- Better SNR model (e.g., mpsim by Felipe)
- Should make parameter input names consistent with the rest of gnsrefl