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GNSS-IR WATER LEVELS

BACKGROUND ON MODELS AND METHODS NEEDED/USED FOR WATER MONITORING

GNSS-IR WATER LEVELS

- Measuring water levels using GNSS-IR is fundamentally pretty simple
- However there are some other factors we have to take into account
- In some ways it can be considered easier than say snow – the water surface (over the footprint size) can generally be considered to be “flat”
  - Although it may not necessarily be considered to be “smooth”
- Water Levels can change rapidly over a satellite arc and therefore requires care
- For lakes and rivers (mainly) we can still use daily_avg but for sea we need to use subdaily
- Water may change to ice…
- The installation itself can be problematical and influence what you will get. So we will look at that first

GNSS-IR WATER LEVELS : SITE SELECTION/INSTALLATION

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- Two classes here
  - Your own installation where you have considered all the factors for a good site
  - A site pre-installed for purposes of vertical land movement, tectonics, surveying etc where you have had no control on its installation
- Ideally you would like a site with a good azimuth range, with minimal clutter in the field of view
- In addition it is good to have a modern receiver recording multi-GNSS in RINEX 3 with a sufficient sampling rate
- Also no elevation cut-off settings in the receiver

GNSS-IR WATER LEVELS : “PERFECT” SITE (THEORETICALLY)

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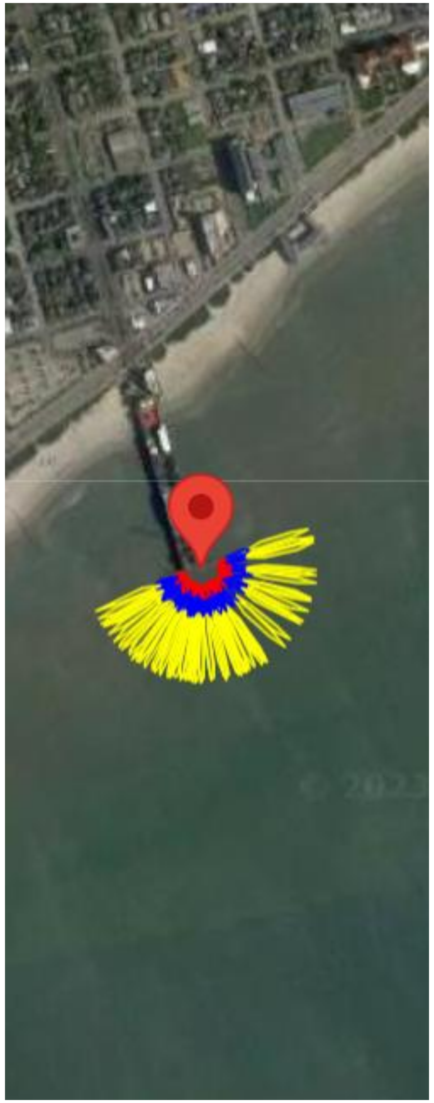
- Full 360 degree reflection zones
- No obvious clutter in the reflection zone area leading to extra unwanted multipath
- Good height above the water surface to ensure sufficient number of SNR cycles
- Antenna in a good location on the platform so reflected and direct signals are not blocked

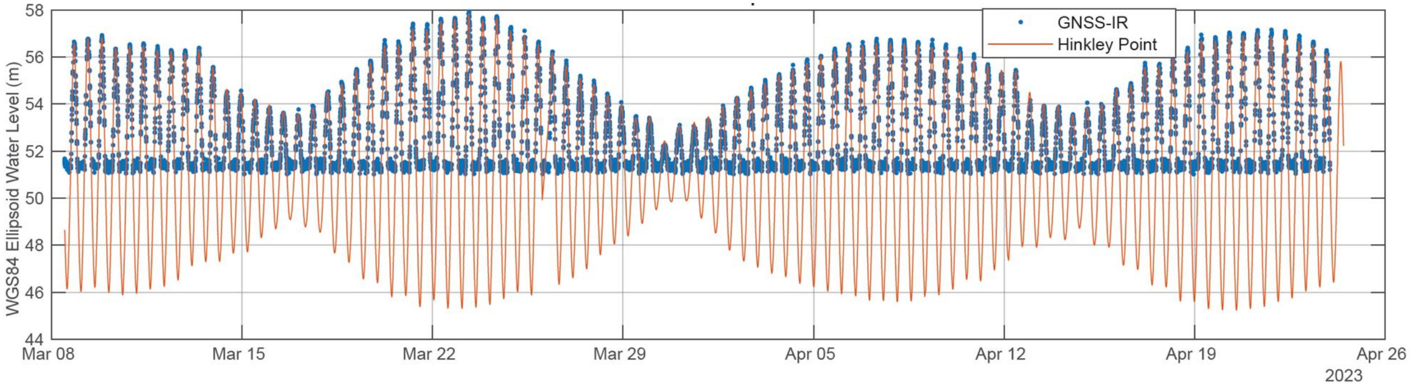
GNSS-IR WATER LEVELS : "NOT SO PERFECT" SITE

- This is similar to the previous site
- About 20 m from water surface
- Again no obvious clutter in the reflection zone
- Antenna is mounted on one side of the platform
- Potential for obstruction of the signals and multipath from the platform itself
- Limits the azimuth range

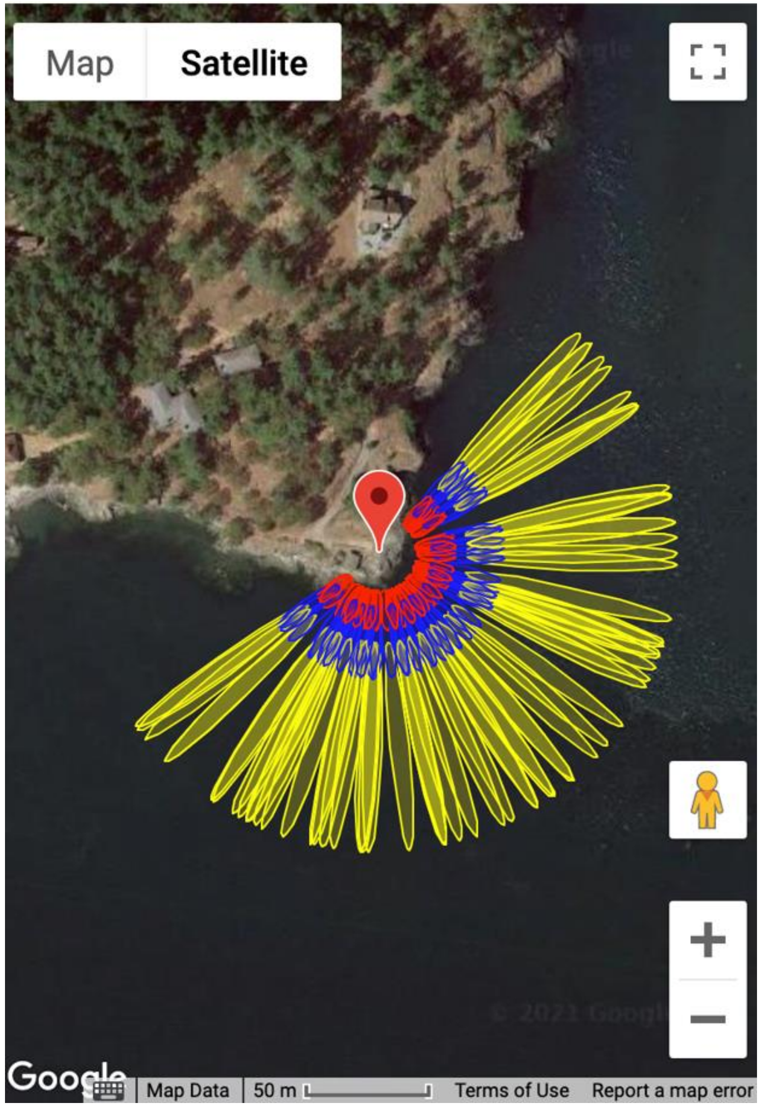
GNSS-IR WATER LEVELS : LAND SITES



- More likely you are going to install a GNSS-IR on land
- This will always limit the useable azimuth range to generally below 180 degrees
- Piers are a good option
  - Reasonable height above the water surface
- Note in this case at the pier on the left the tidal range is so large that the reflection zone "dries" out twice daily



GNSS-IR WATER LEVELS : MORE TYPICAL SITE



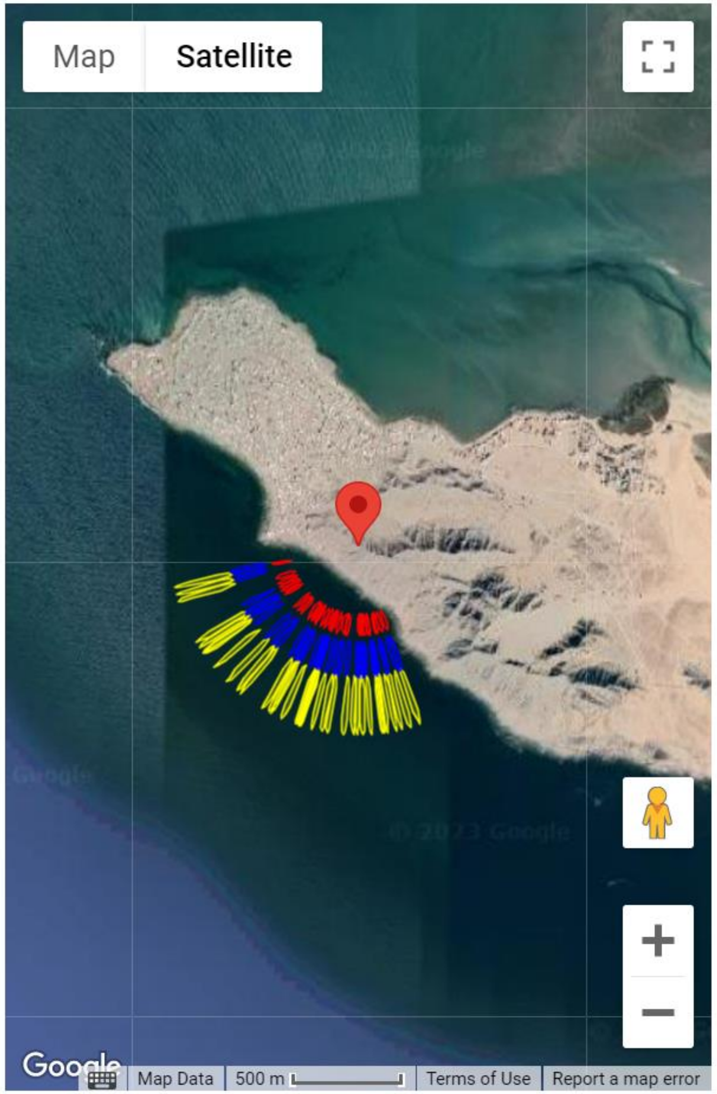
- These are more typical but good sites on headlands
- Pretty good azimuthal range
- Again largely uncluttered in reflection zone
- Site on the left does have islands that can mean we loose low elevation angle data.

GNSS-IR WATER LEVELS : MORE CHALLENGING SITE

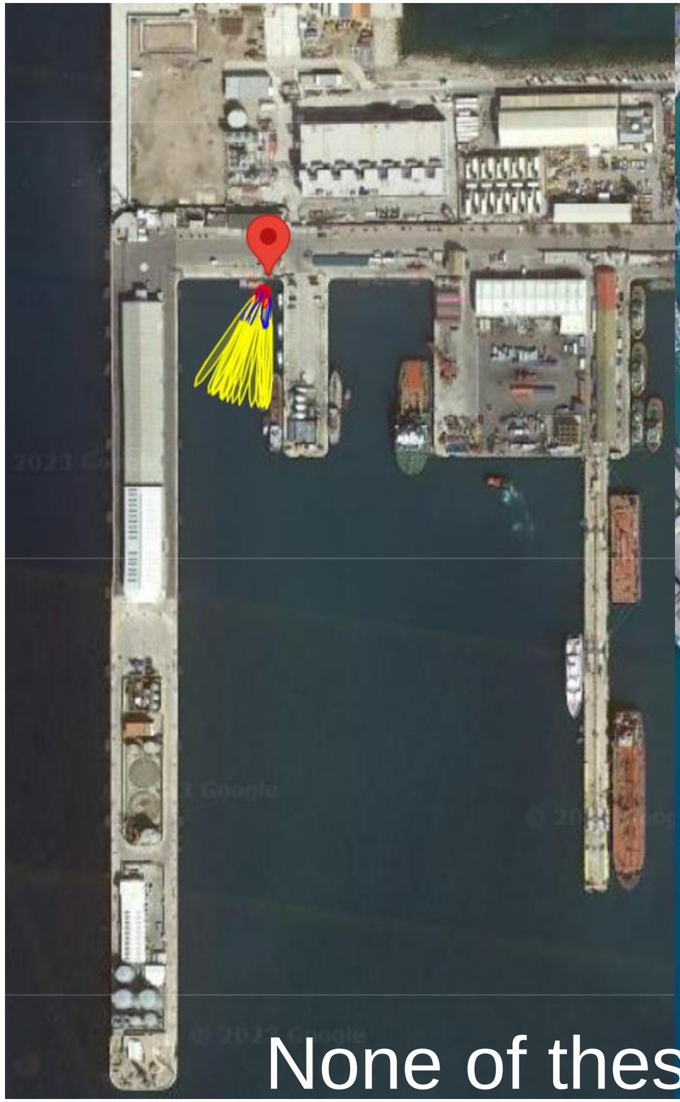
- This site is on the side of a hill at around 63 m
- Azimuth range is more limited
- Possible to get multipath off the hillside itself

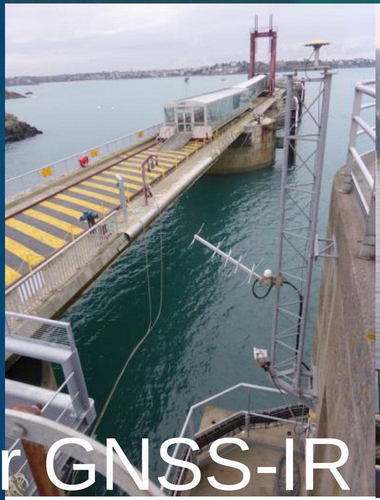
Station: tnpp
Latitude: 31.3355186
Longitude: -113.6316366
Ellipsoidal Height(m): 27.636
Reflection Ht. (m) : 62.766
Elevation Angles (deg) : 5,7,10
Azimuth Angles (deg) : 160 to 260
Constellation : GPS
Frequency: L1

Return to the Reflection Zone API



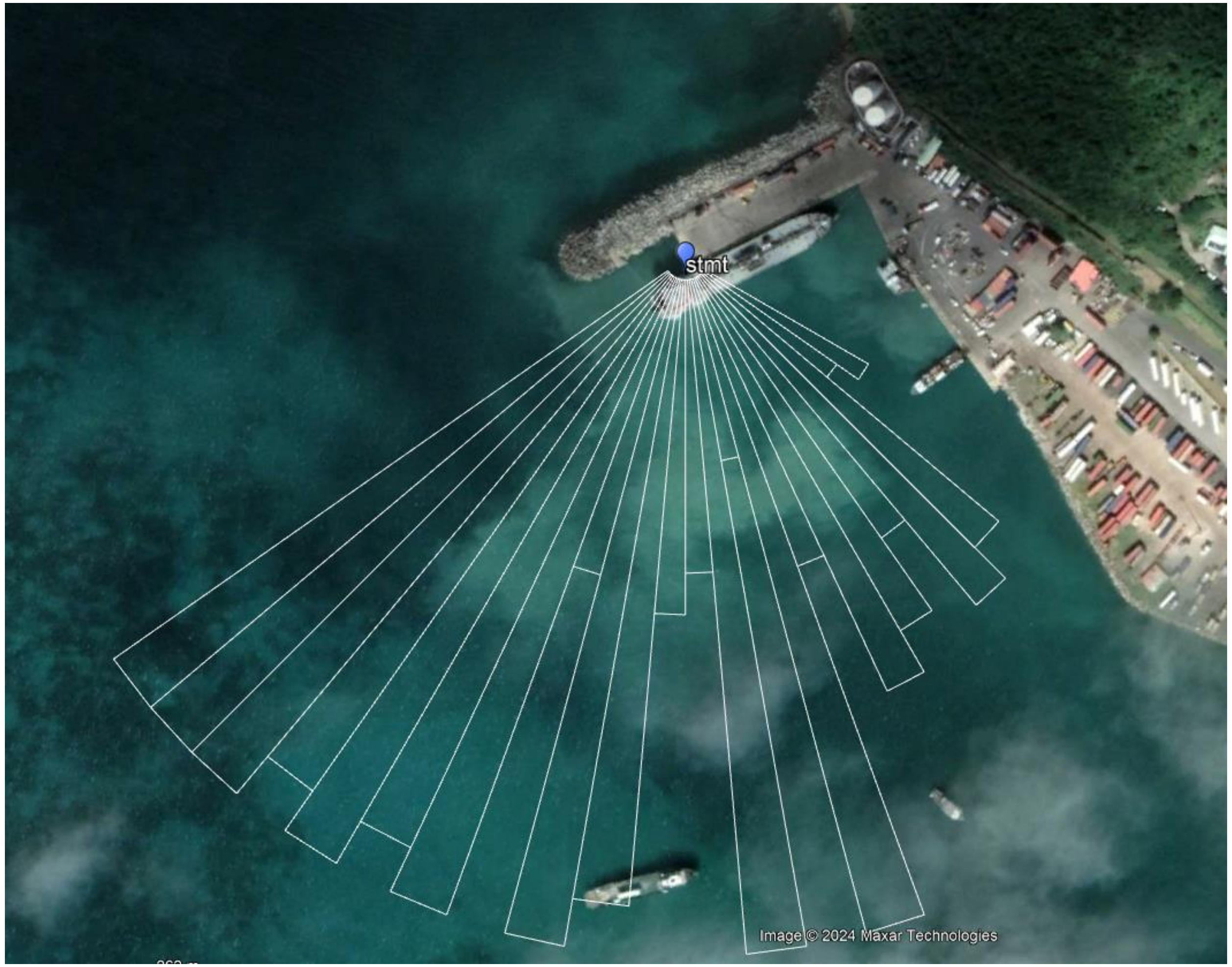
GNSS-IR WATER LEVELS : VERY CHALLENGING SITES





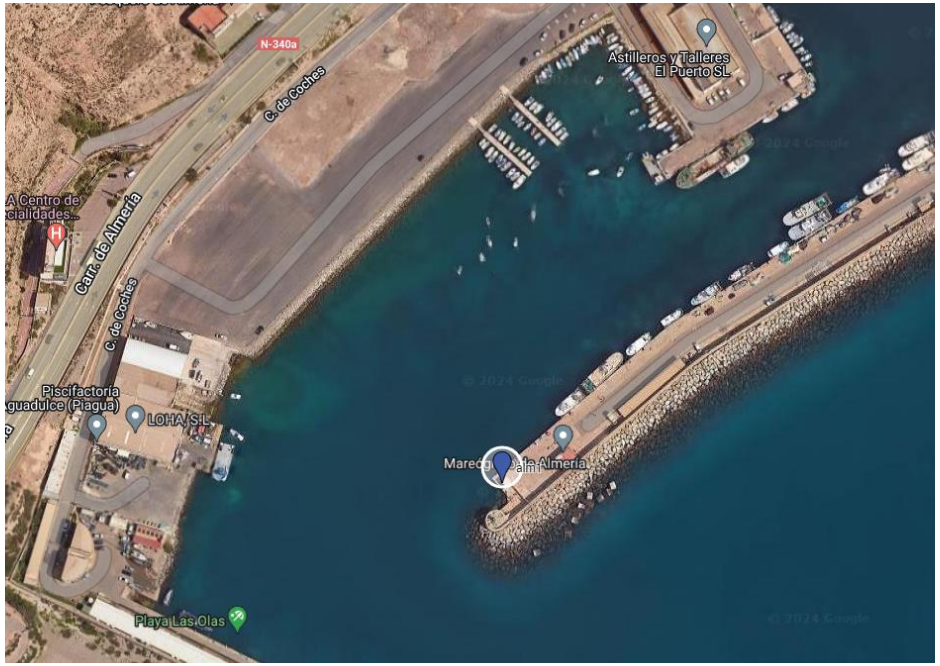

None of these sites were installed for GNSS-IR purposes

GNSS-IR WATER LEVELS : VERY CHALLENGING SITES

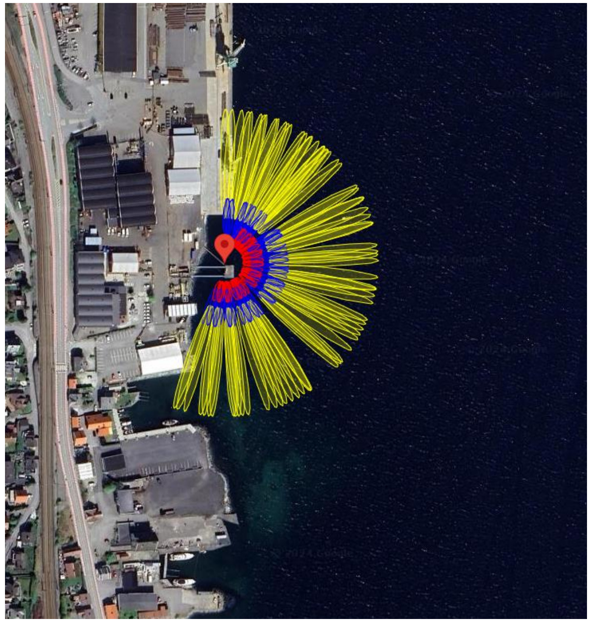


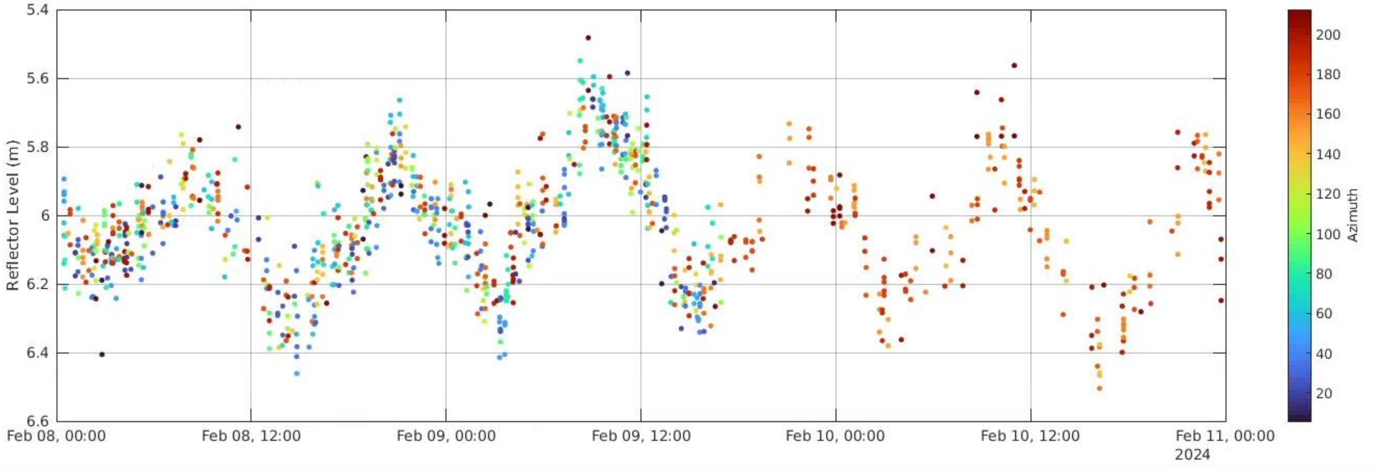
This site was not installed for GNSS-IR purposes

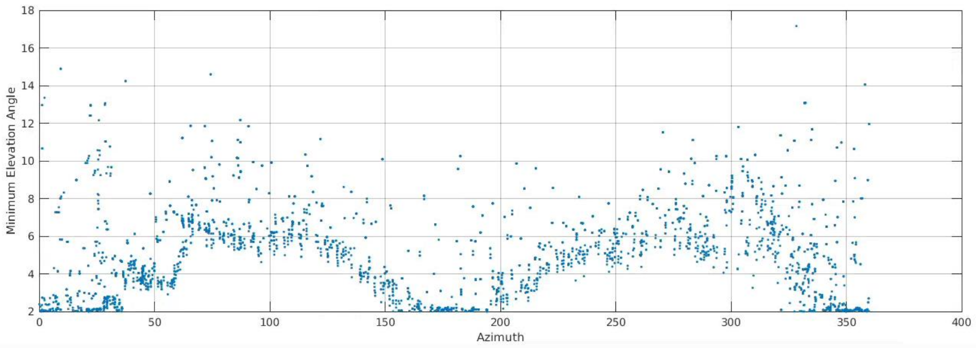
GNSS-IR WATER LEVELS : NO-GOES



NEW EXAMPLE FROM TODAY : SNES NORWAY







GNSS-IR WATER LEVEL : TIME VARYING SURFACE ($\dot{H}$) EFFECT

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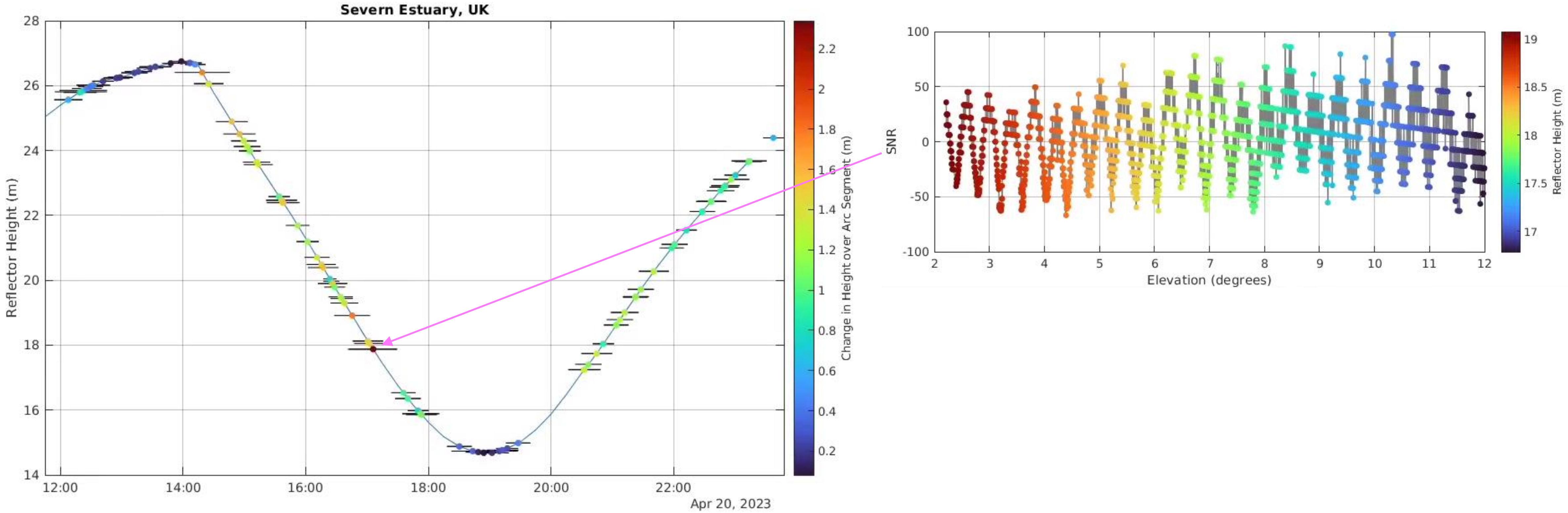
- Unlike using GNSS-IR for other hydrologic applications water levels can vary rapidly within the time of a satellite pass mainly as a result of tides



GNSS-IR WATER LEVEL : TIME VARYING SURFACE ($\dot{H}$) EFFECT

- This causes a shift in the peak of the LSP
  - Instead of the oscillation frequency being $f = \frac{2}{\lambda}$ h it becomes $f = \frac{2}{\lambda}\left(h + \frac{\dot{h}\ \tan\varepsilon}{\dot{\varepsilon}}\right)$
  - Where $\dot{h}$ is the rate of change in the height of the reflector
  - And $\dot{\varepsilon}$ is the rate of change in the elevation angle.
- If the arc is sufficiently short then we can assume that both $\dot{h}$, $\dot{\varepsilon}$ and $\tan\varepsilon$ are constants (we take the average)

HOWEVER that still means we need to “know” $\dot{h}$ to get h!

GNSS-IR WATER LEVEL : TIME VARYING SURFACE ($\dot{H}$) EFFECT

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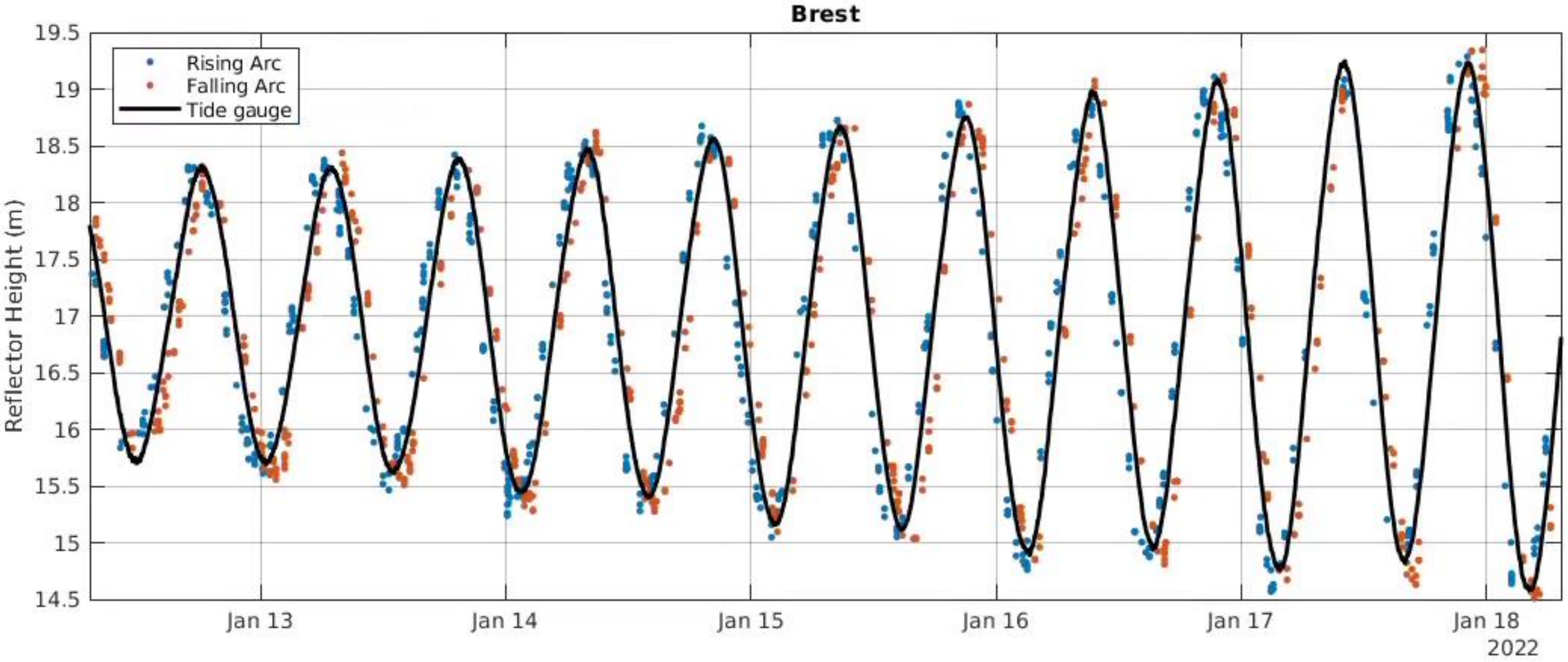

- Rising arcs on a rising tide have a larger than expected reflector height same for falling arcs on a falling tide
- Falling arcs on a rising tide and rising arcs on a falling tide have a lower than expected reflector height

GNSS-IR WATER LEVEL : TIME VARYING SURFACE ($\dot{H}$) EFFECT

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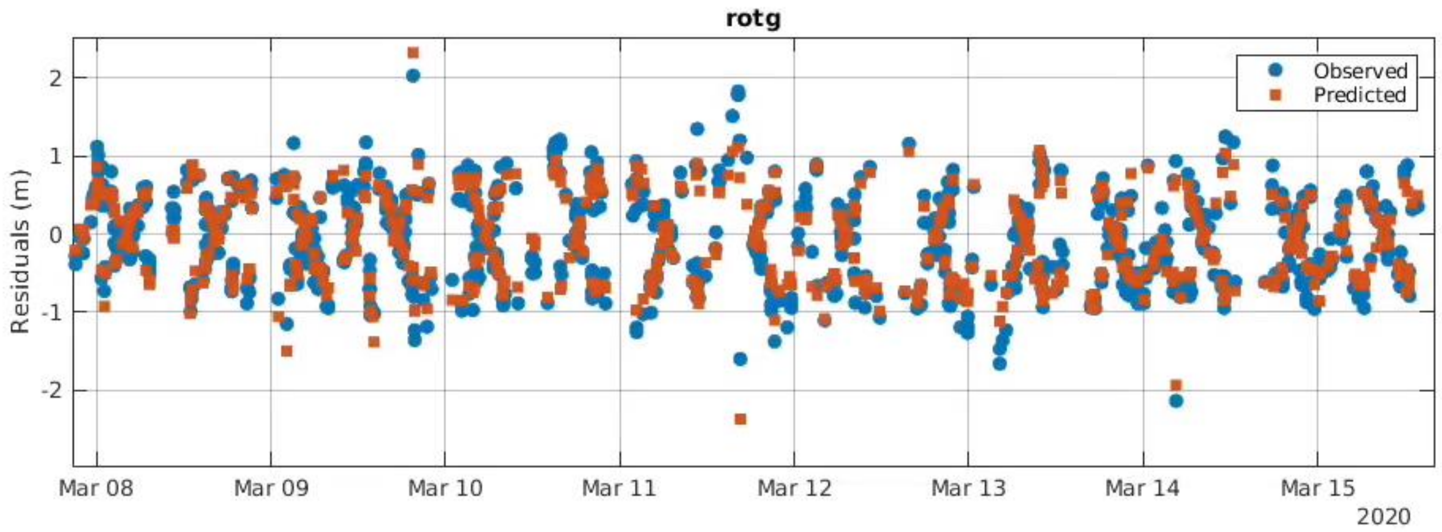
- ROTG here has a tidal range of nearly 10 metres
- And a $\dot{h}$ of up to a few metres

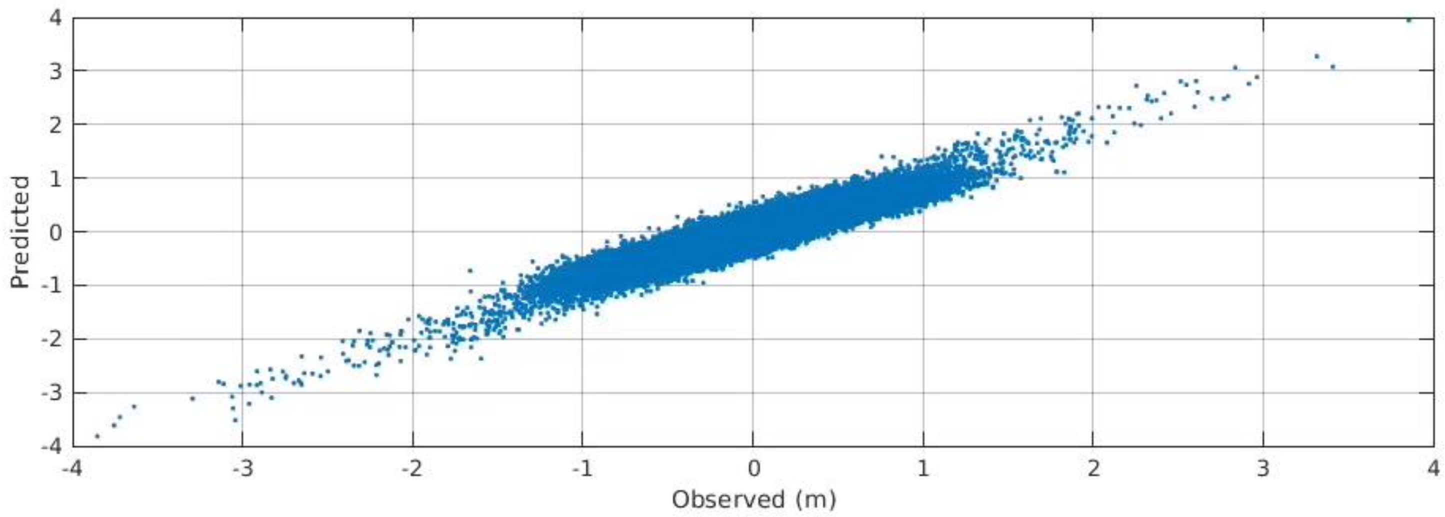
So how do you account for the $\dot{h}$ effect?

Process as normal and then fit a curve to the results and then take its gradient and calculate $\frac{\dot{h}\ \tan\varepsilon}{\dot{\varepsilon}}$

The curve can be a spline or a tidal harmonic fit (if the main cause is tides)

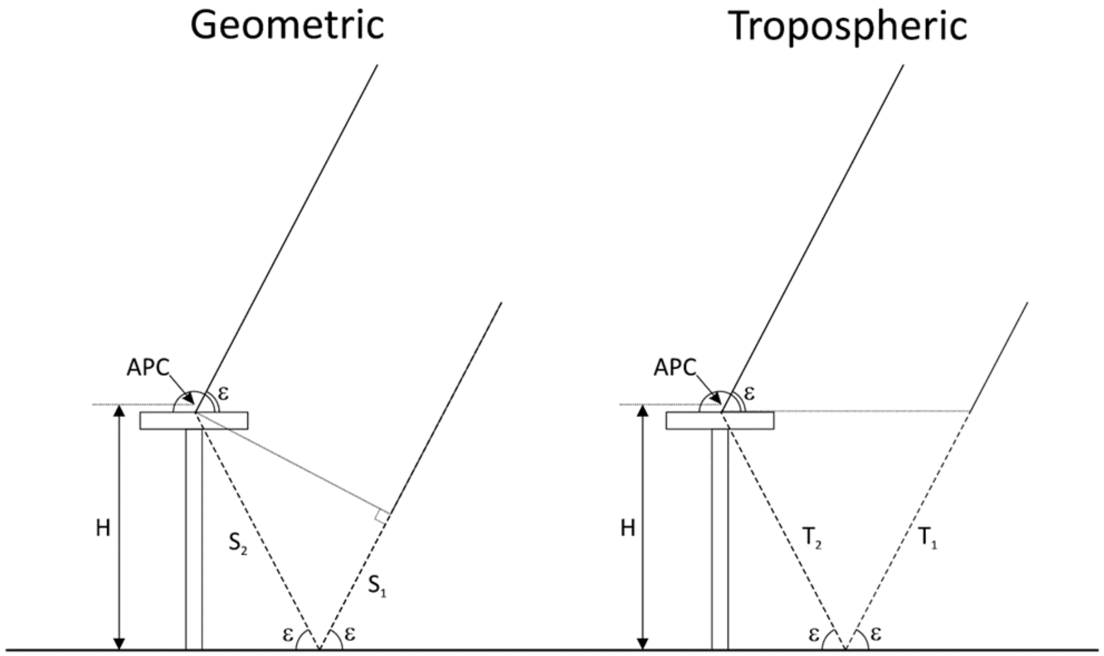
Beware of using long arcs!





GNSS-IR WATER LEVEL : TROPOSPHERIC DELAY

- Any microwave signal that propagates through the neutral atmosphere (troposphere) will be delayed
- Most GNSS positioning processing schemes estimate tropospheric zenith delays alongside position coordinates using a mapping function
- GNSS-IR will also experience a tropospheric delay effect



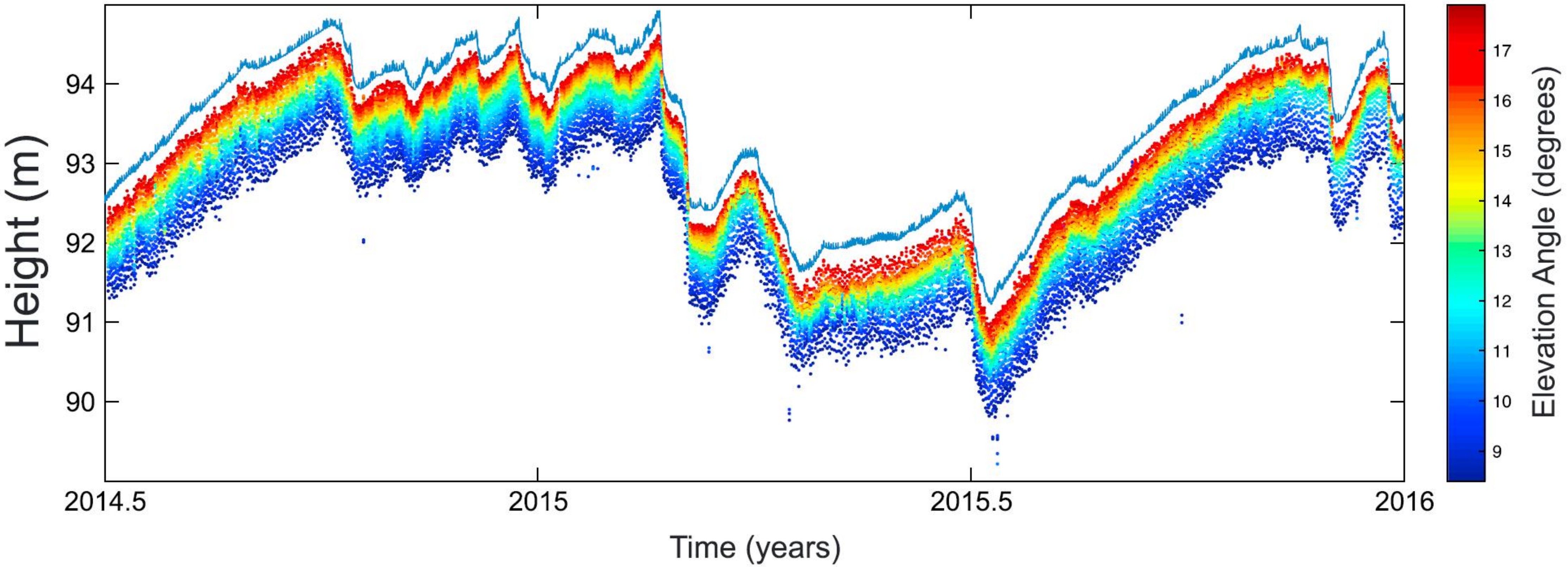
GNSS-IR WATER LEVEL : TROPOSPHERIC DELAY

- Like the time varying surface effect the tropospheric delay will cause a shift in the estimated reflector height
- Instead of the oscillation frequency being $f = \frac{2}{\lambda}$ h it becomes $f = \frac{2}{\lambda}\left(h + \frac{1}{2}\frac{\delta\tau_T}{\delta \sin \varepsilon}\right)$
- This bias is always negative and is elevation and height dependent
- It is often ignored when the reflector height is relatively small (few m) but cannot be ignored for high sites
- It is easily corrected by “Stretching” the elevation angles prior to calculating the LSP
- The main change is a height bias but if there are tides then it will also appear in the estimated tidal harmonics as a reduction in the amplitude of a few percent

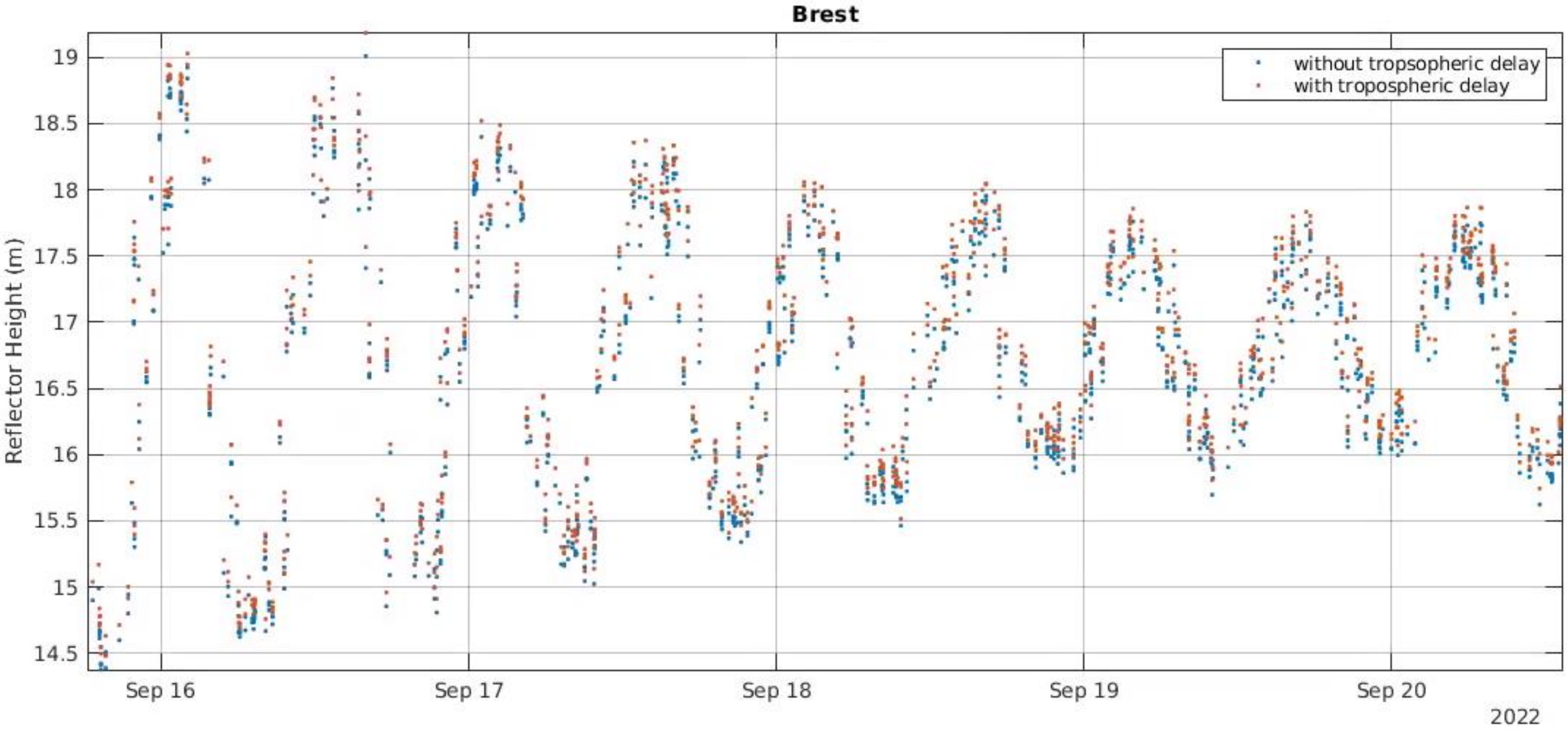
GNSS-IR WATER LEVEL : TROPOSPHERIC DELAY

KYDH : Dale Hollow Lake, Kentucky Antenna 90+ m above lake

Elevation angle is the average elevation angle of the satellite arc eg 5-7 (6), 6-8 (7) etc

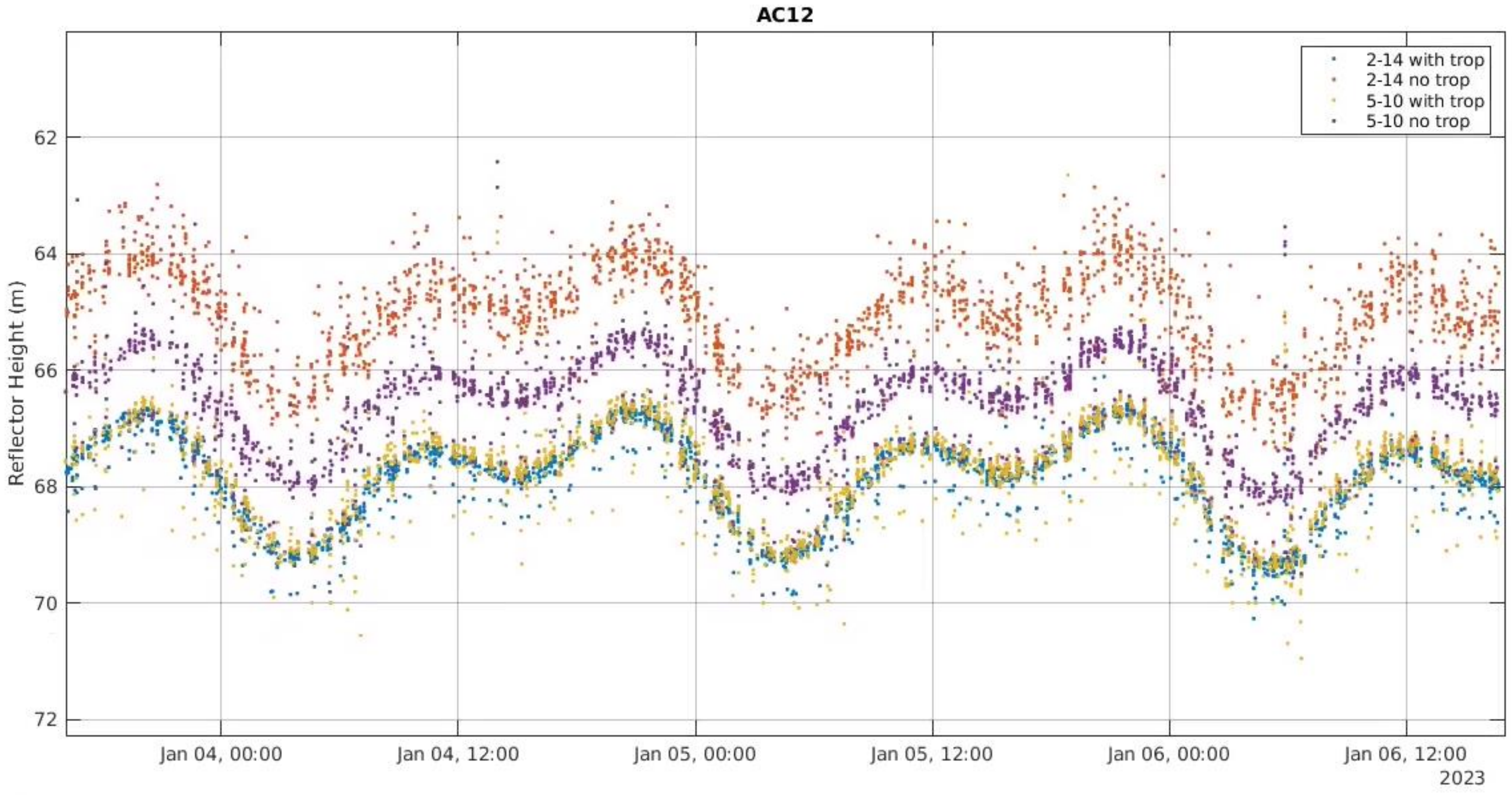


GNSS-IR WATER LEVEL : TROPOSPHERIC DELAY



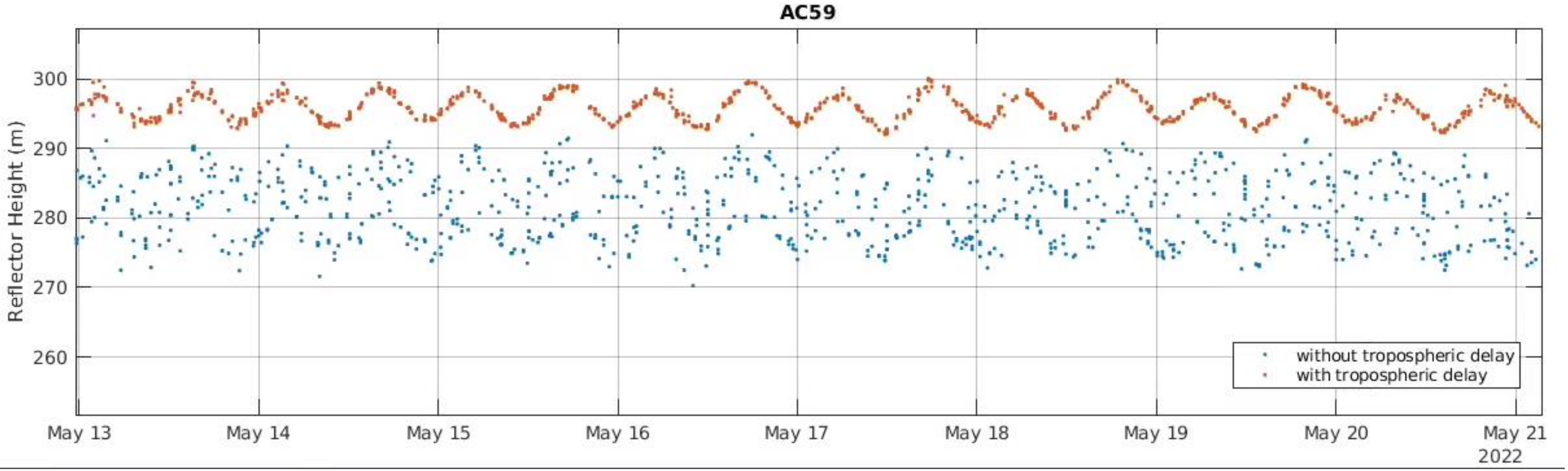
For a site like Brest, 17 m above the water you can just see on offset in the results with/without tropospheric delay applied. The median difference is 11.5 cm

GNSS-IR WATER LEVEL : TROPOSPHERIC DELAY



For AC12 68 m above the water you can see an offset of around 4 m (2-14 degree) and 2 m (5-10 degree) but also an increased scattering in the non tropospheric delay results

GNSS-IR WATER LEVEL : TROPOSPHERIC DELAY



For AC59 295 m above the water you can see an offset of over 10 m and nonsense results and a frequency dependence.

GNSS-IR WATER LEVEL : INTER-FREQUENCY BIAS

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- In GNSS processing it is well known that the estimated position are related to what is known as the antenna phase centre (APC) (not a physical point)
- The APC is different for different frequencies
- The GNSS community uses special techniques to measure the APC for all major antennas
- In GNSS-IR the reflected heights are also relative to some phase centre.
- However they are not the same as in positioning
- This means if we used multiple frequencies we will get different reflector heights

GNSS-IR WATER LEVEL : INTER-FREQUENCY BIAS

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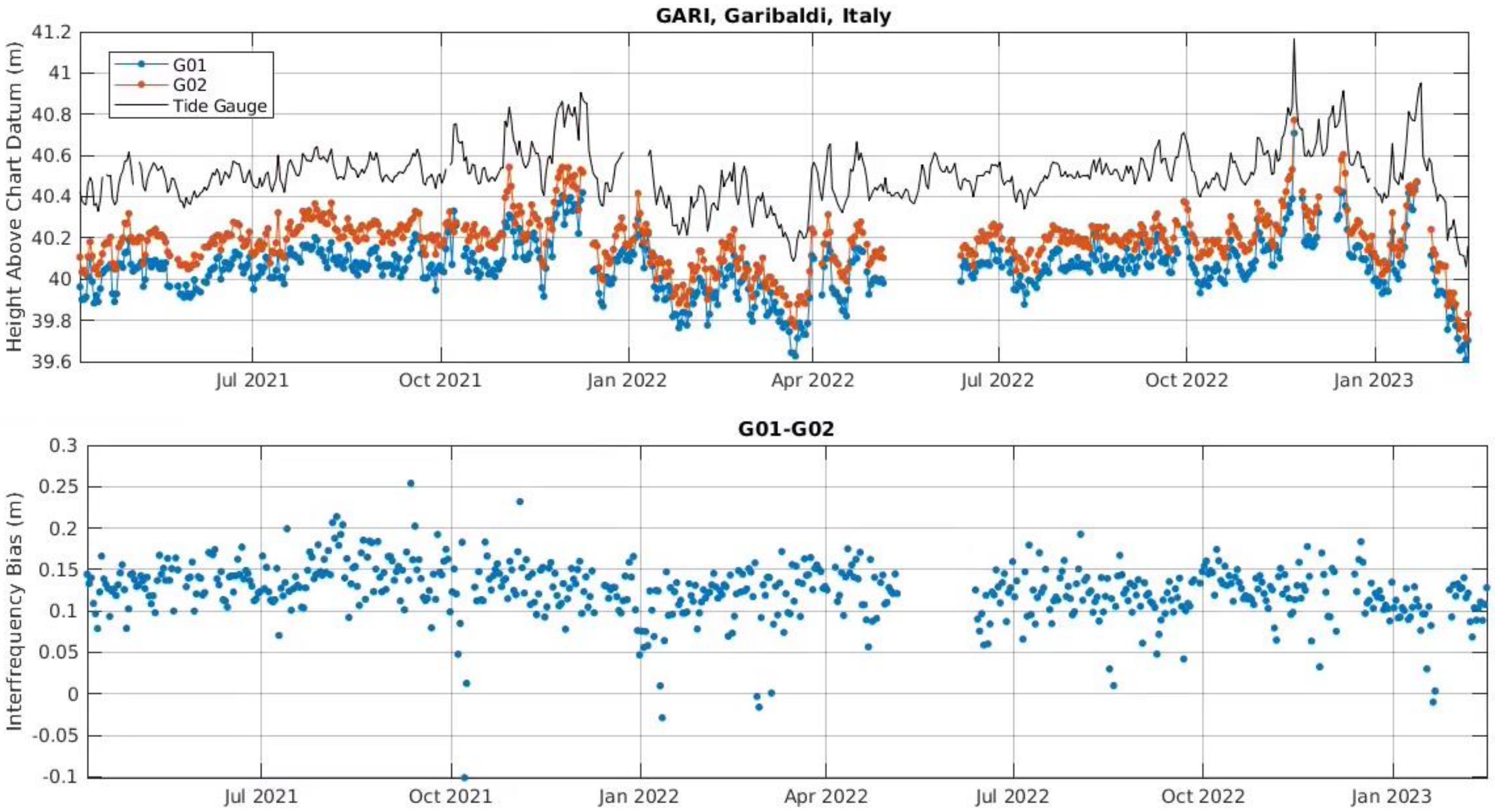
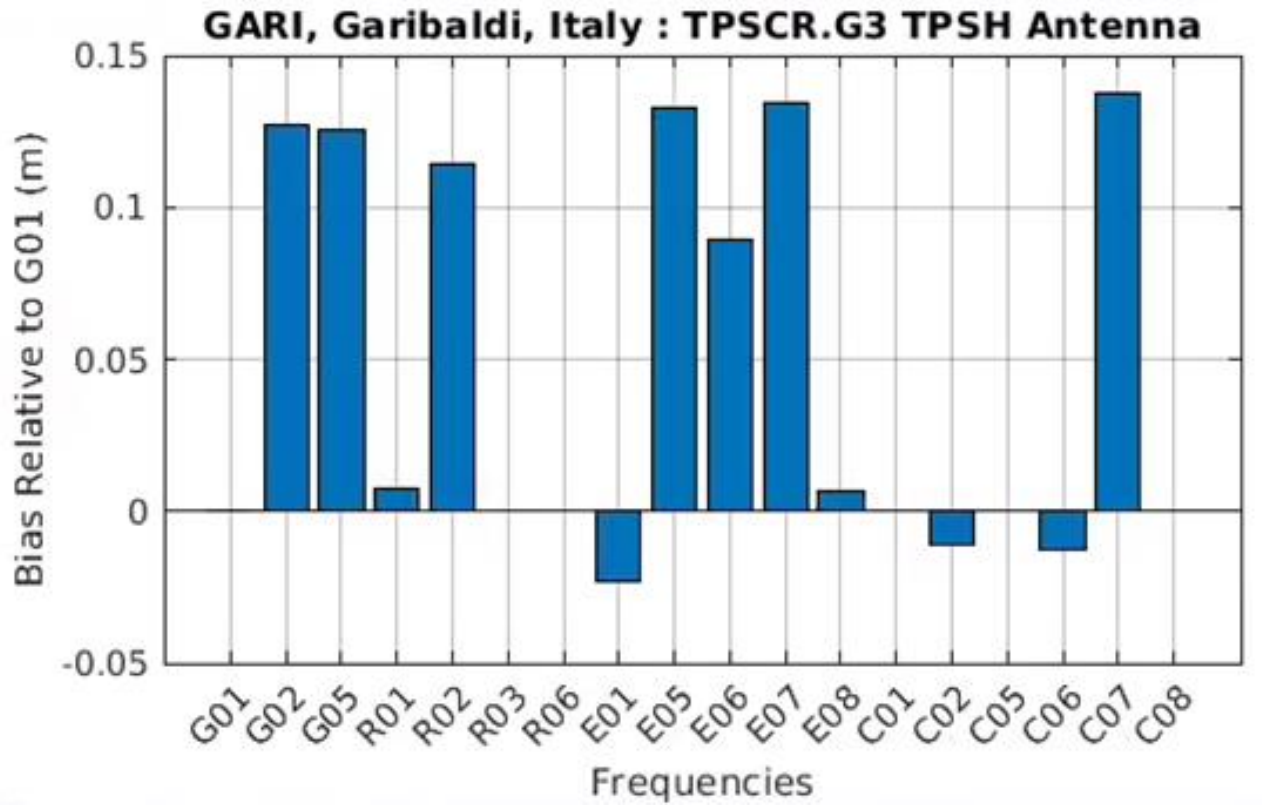
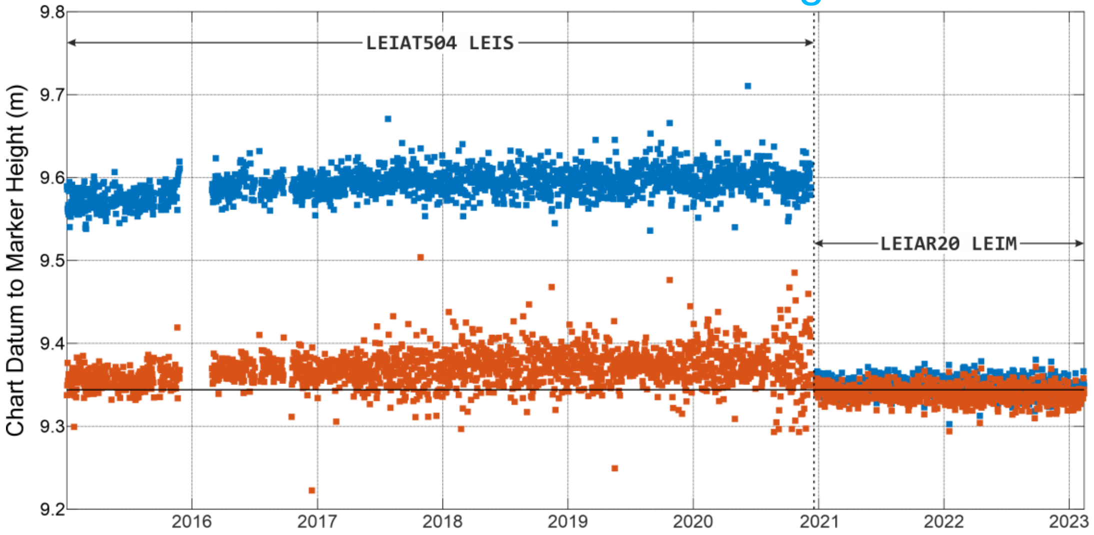


GNSS-IR WATER LEVEL : INTER-FREQUENCY BIAS



- Note the interfrequency bias is different for different antennas

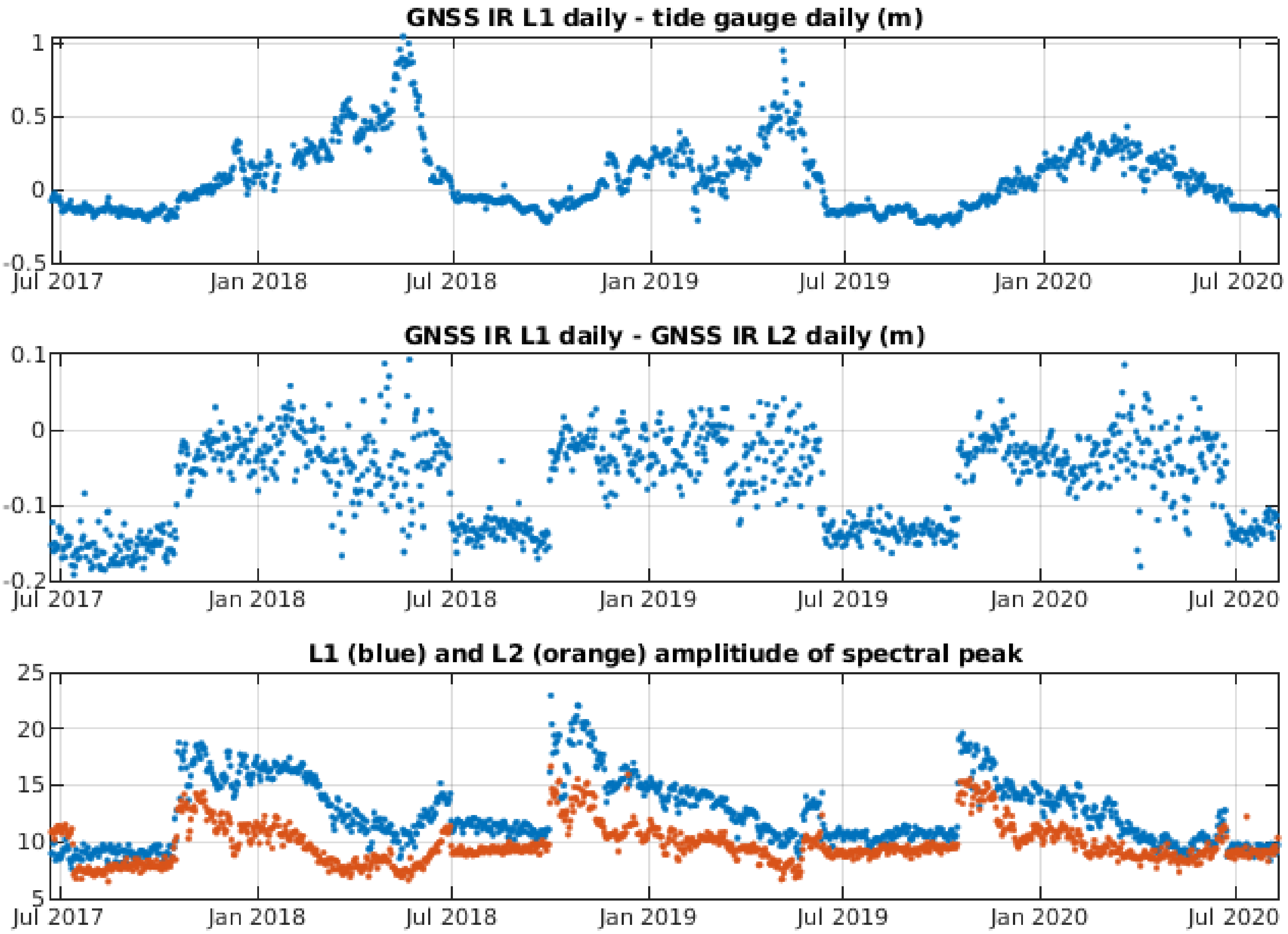
Site : TN01 : Blue G01 : Orange G02



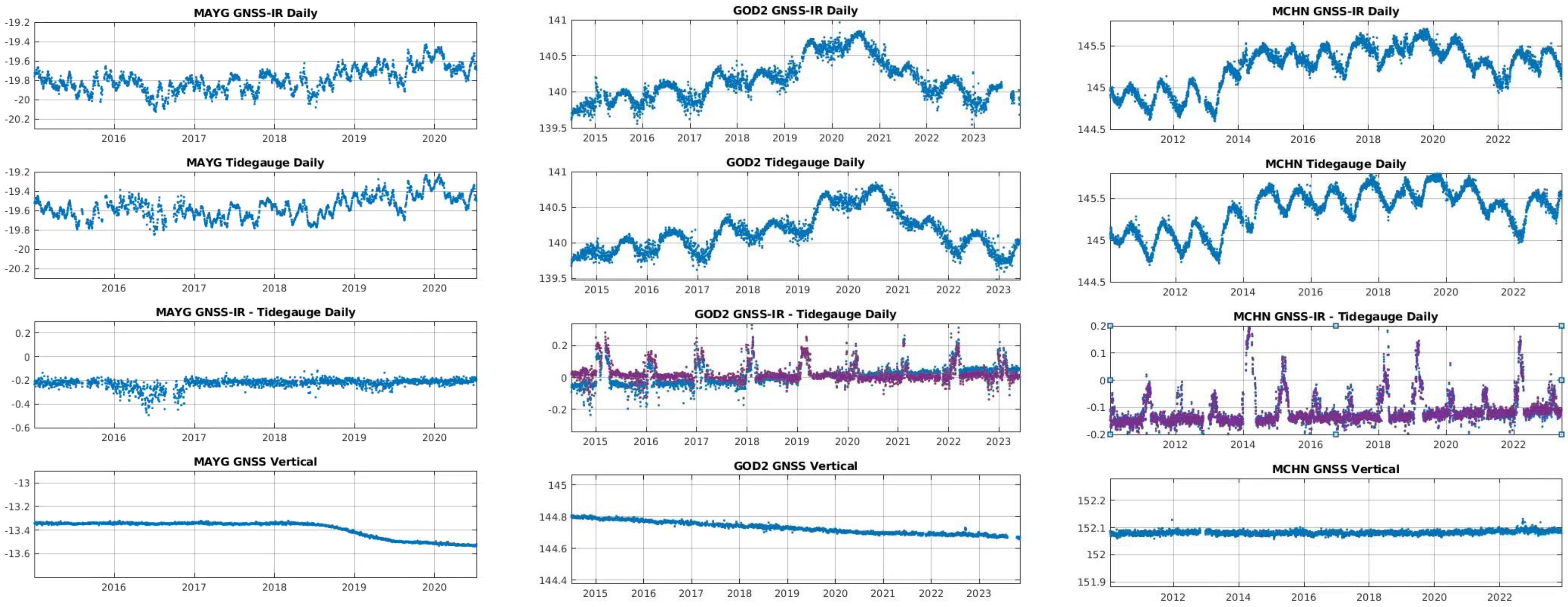
In general the inter-frequency bias is removed by mapping them onto the G01 signal

GNSS-IR WATER LEVEL : ICE / WATER BIAS

- In polar regions we may find that the sea or lake freezes.
- At that point we will be measuring the ice and may get differences from a nearby tide gauge
- Frozen water has a different interfrequency bias than water (nearly zero for ice)
- The power of the signal is also larger on ice
- All can be used to indicate water/ice



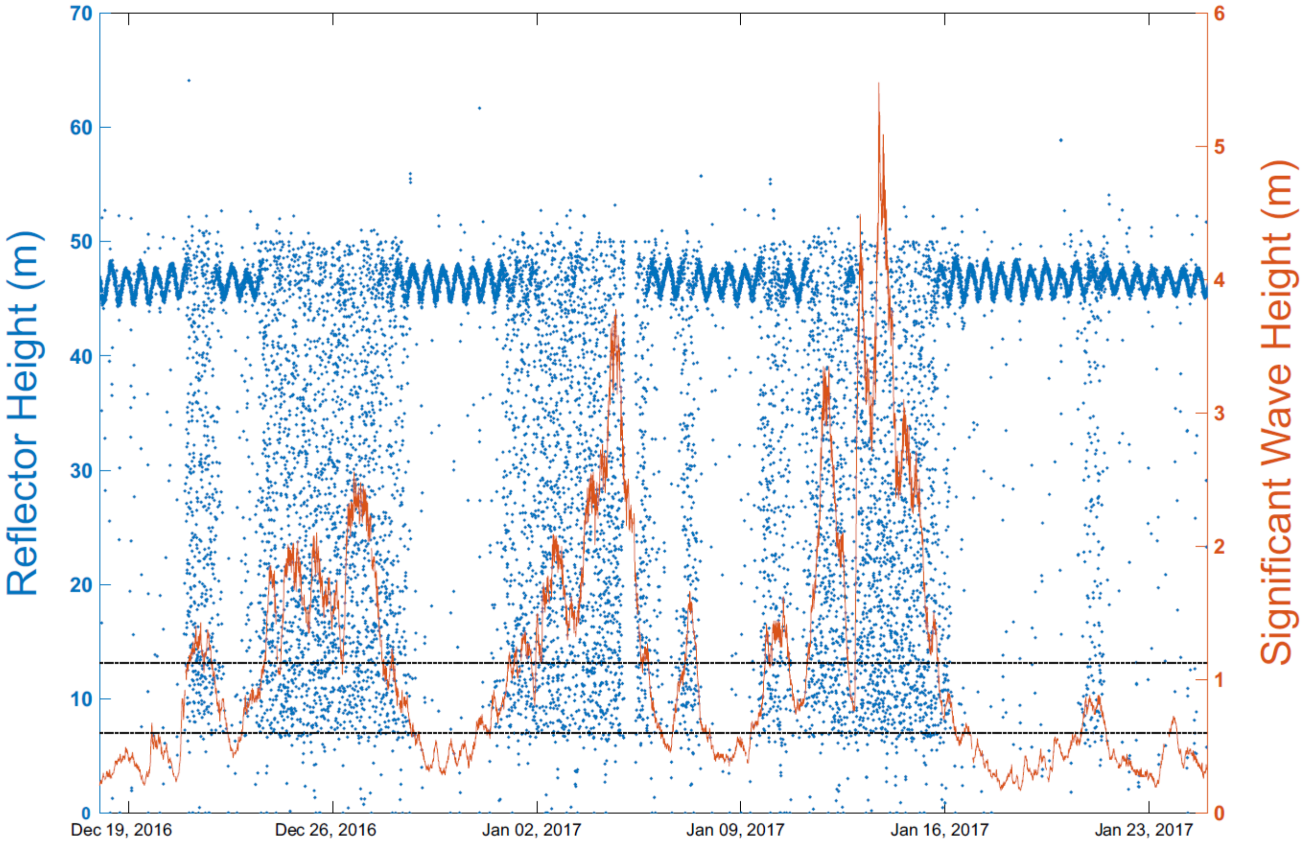
GNSS-IR : THEY ALSO MEASURE POSITION



GNSS-IR WATER LEVEL : EFFECT OF WIND/WAVES

- If the waves become too large then the reflected signal decorrelates and no heights can be estimated (random roughness)

BLIGH BANK II Windfarm
Substation South West North Sea



GNSS-IR WATER LEVEL : EFFECT OF WIND/WAVES

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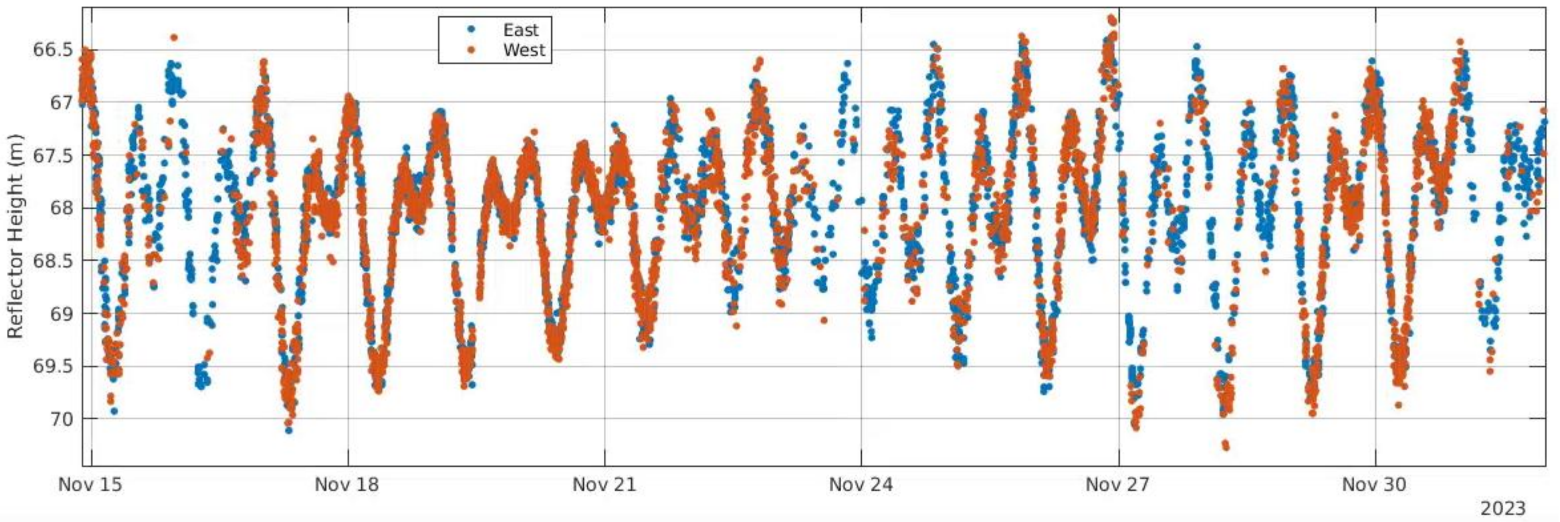
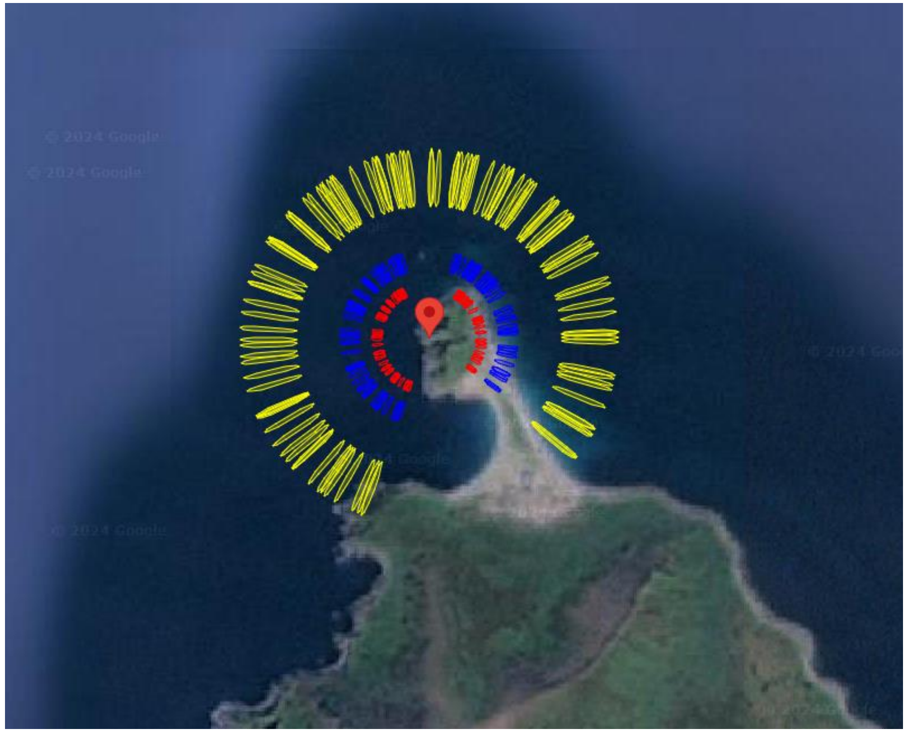
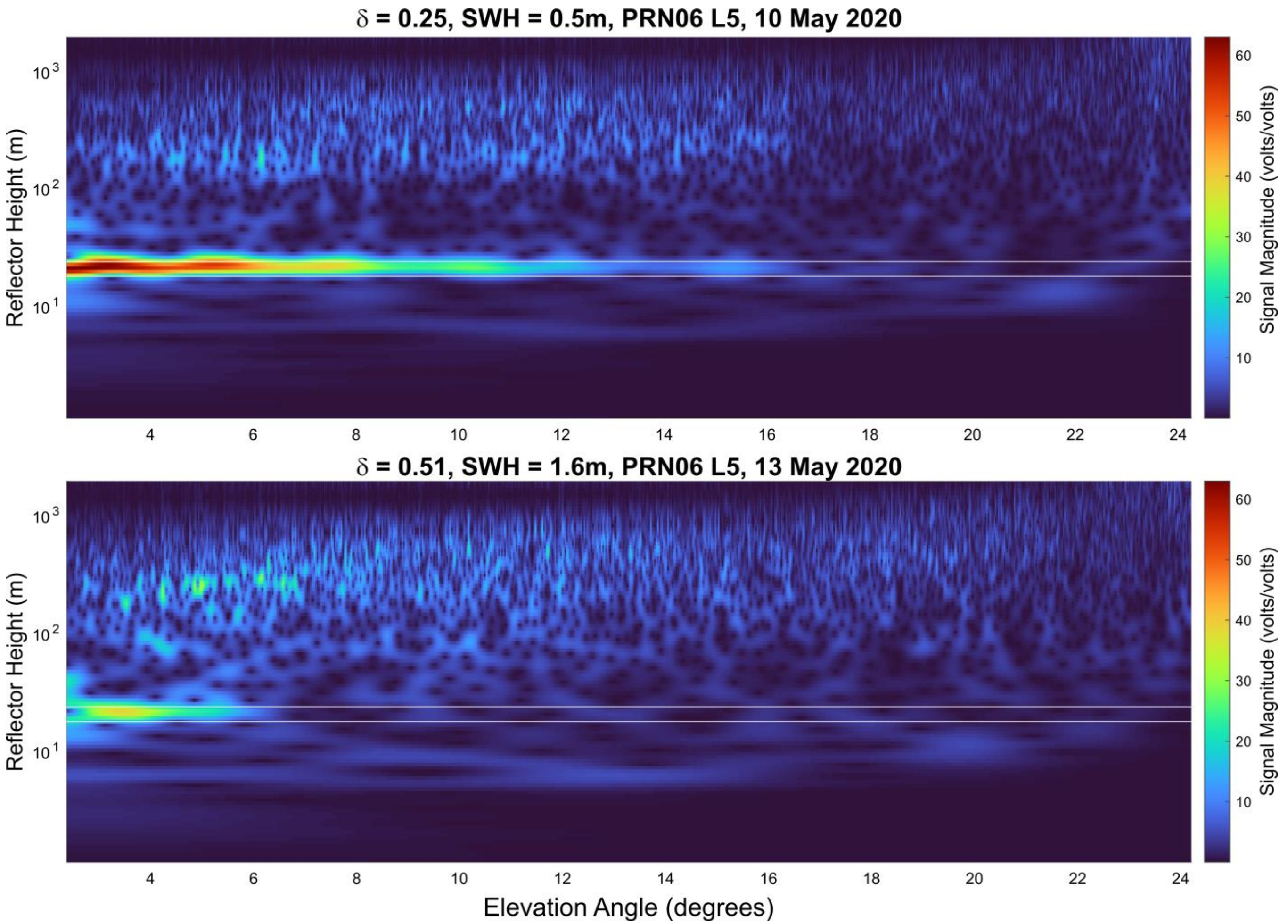
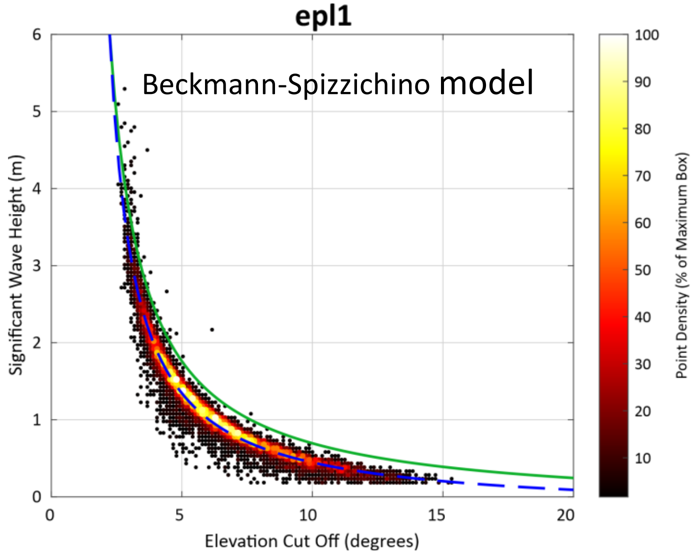
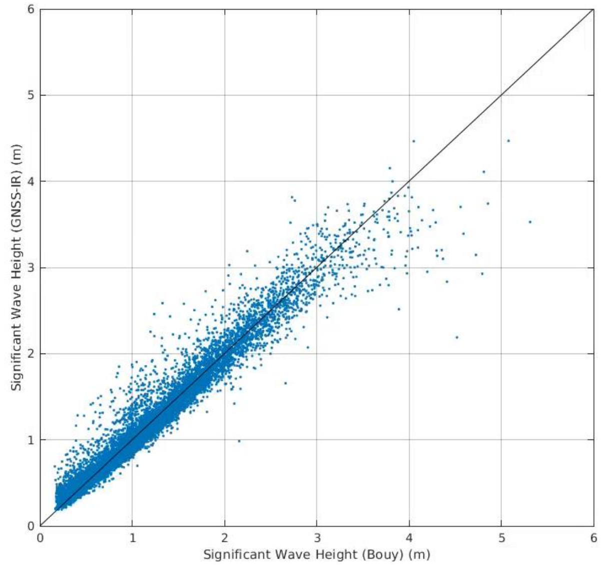




GNSS-IR WATER LEVEL : EFFECT OF WIND/WAVES





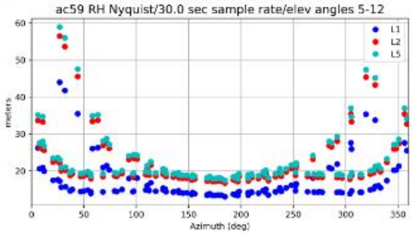


Curve depends on
- wavelength of signal
- height of antenna
- period/wavelength of waves

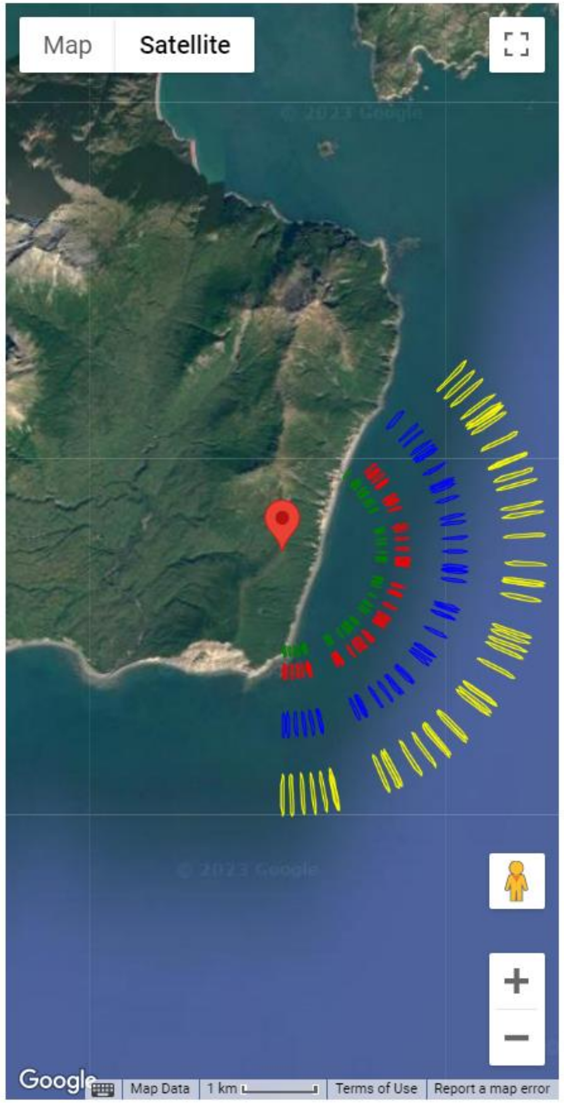
Beckmann, P. and A. Spizzichino (1987). The scattering of electromagnetic waves from rough surfaces.

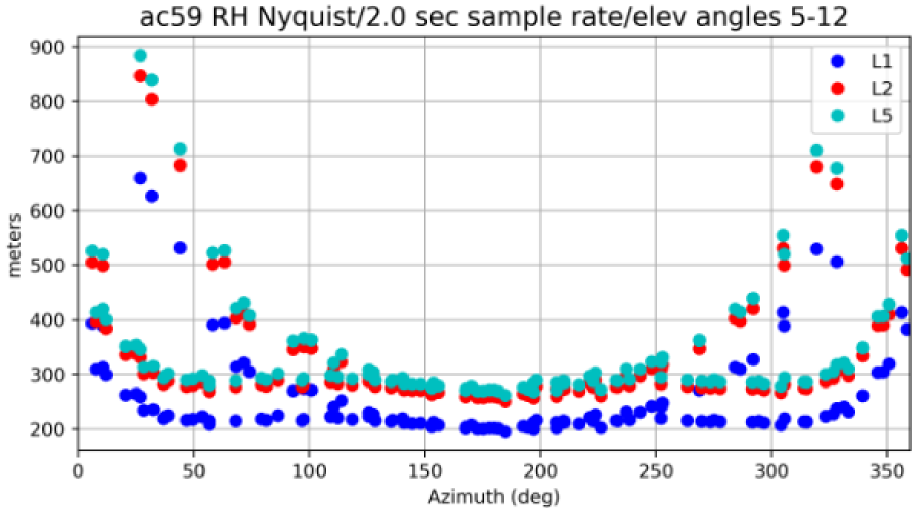
MAXIMUM RESOLVABLE REFLECTOR HEIGHT

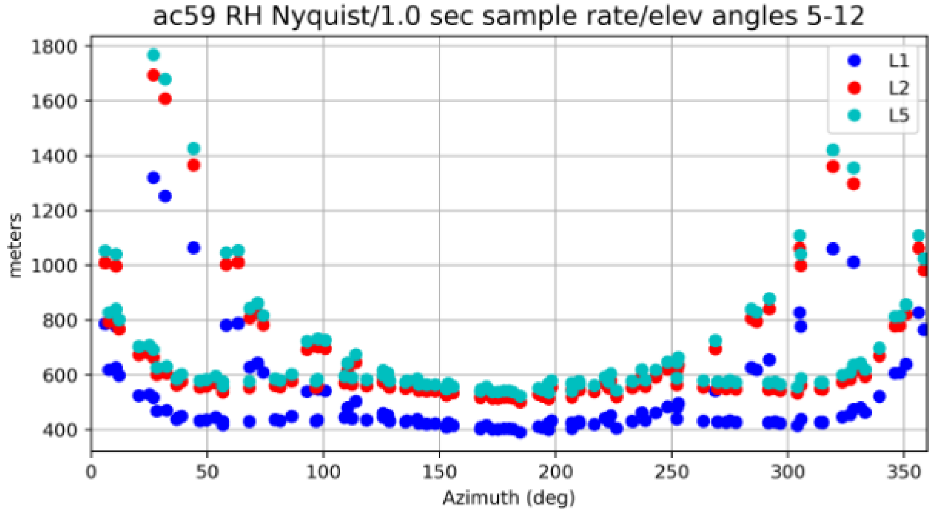
Station: ac59
Latitude: 59.56719883
Longitude: -153.58520038
Ellipsoidal Height(m): 308.546
Reflection Ht. (m) : 295.526
Elevation Angles (deg) : 5,7,10,12
Azimuth Angles (deg) : 40 to 180
Constellation : GPS
Frequency: L1



Return to the Reflection Zone API



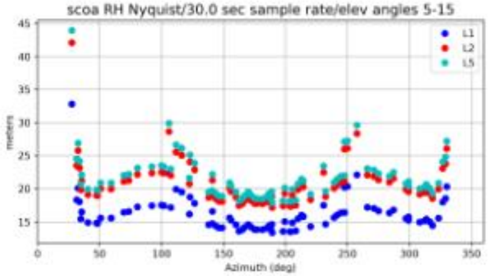




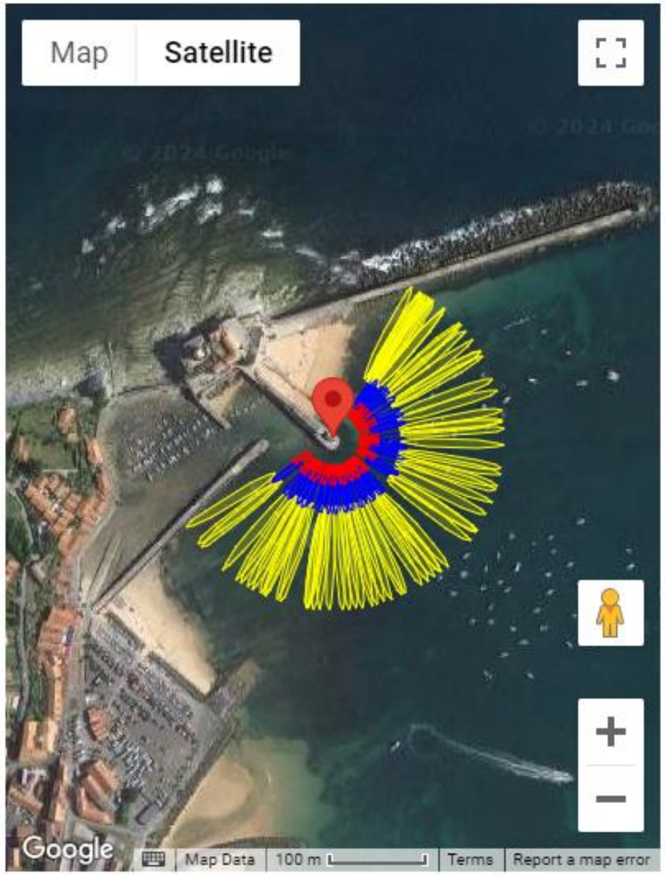
MAXIMUM RESOLVABLE REFLECTOR HEIGHT

National Oceanography Centre

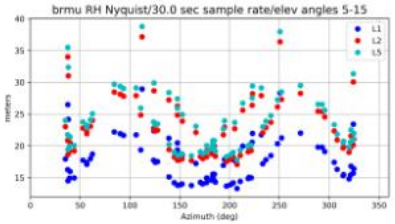
Station: scoa
Latitude: 43.39523504
Longitude: -1.68167808
Ellipsoidal Height(m): 59.486
Reflection Ht. (m) : 9.896
Elevation Angles (deg) : 5,10,15
Azimuth Angles (deg) : 0 to 240
Constellation : GPS
Frequency: L1



Return to the Reflection Zone API



Station: brmu
Latitude: 32.37039869
Longitude: -64.69627344
Ellipsoidal Height(m): -11.631
Reflection Ht. (m) : 22.799
Elevation Angles (deg) : 5,10,15
Azimuth Angles (deg) : 180 to 240
Constellation : GPS
Frequency: L1



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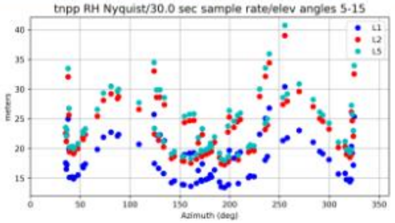
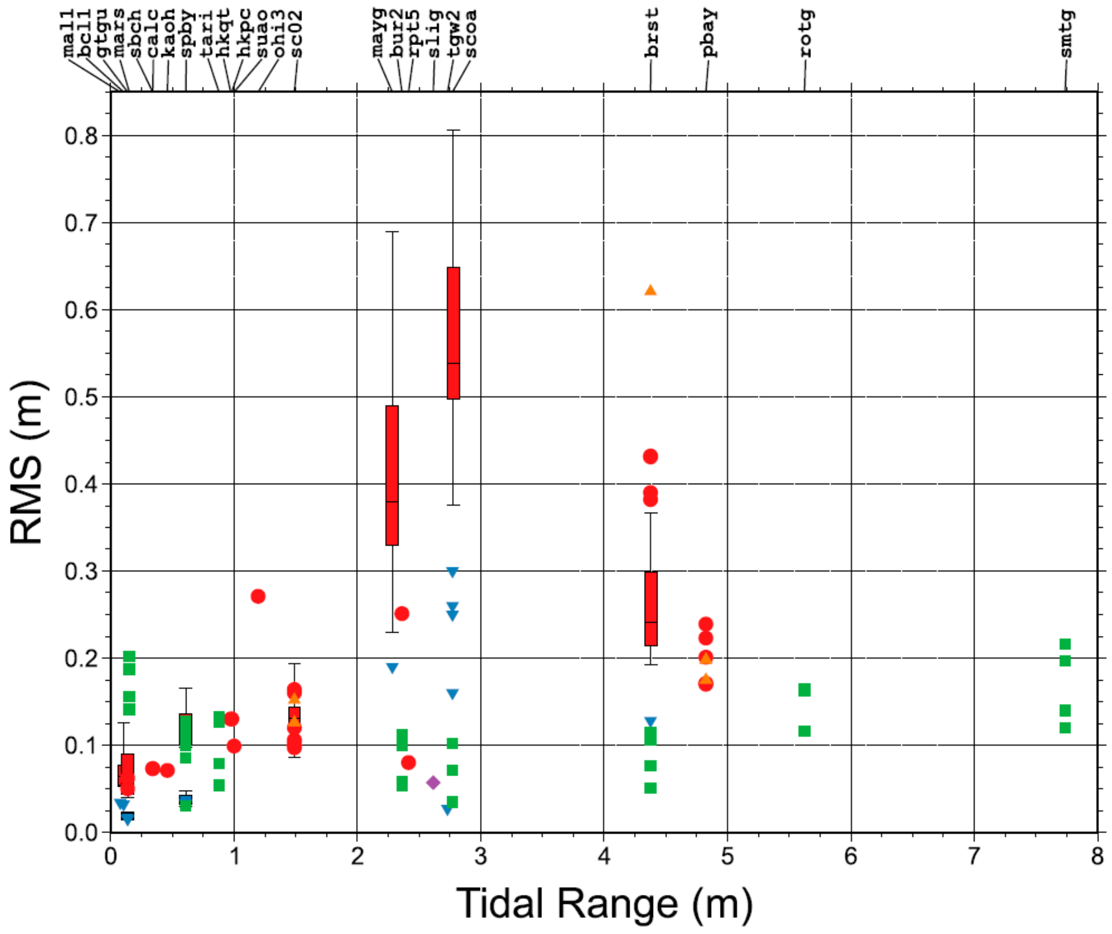
Station: tnpp
Latitude: 31.3355186
Longitude: -113.6316366
Ellipsoidal Height(m): 27.636
Reflection Ht. (m) : 62.766
Elevation Angles (deg) : 5,10,15
Azimuth Angles (deg) : 180 to 300
Constellation : GPS
Frequency: L1



Return to the Reflection Zone API

GNSS-IR WATER LEVEL : UNCERTAINTY

- What is the uncertainty?
- Depends on each site, environment, height, waves, etc
- Depends a bit on methods used (Beware of comparing against a spline – that's not a real comparison)
- LSP individual arcs generally 10-20 cm
- 15 minute arcs least squares fits 5 cm
- Daily results 1-5 cm
- Monthly results 1-2 cm



GNSS-IR WATER LEVEL : UNCERTAINTY