

The logo for the National Oceanography Centre, featuring a white square above a blue square, with the text "National Oceanography Centre" in black.

National  
Oceanography  
Centre

A background image of ocean waves with white foam, overlaid with a blue gradient at the top.

**GNSS-IR WATER LEVELS  
BACKGROUND ON MODELS AND  
METHODS NEEDED/USED FOR WATER  
MONITORING**

- Measuring water levels using GNSS-IR is no different in principle than measuring snow
- However there are some other factors we have to take into account
- In some ways it can be considered easier – 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

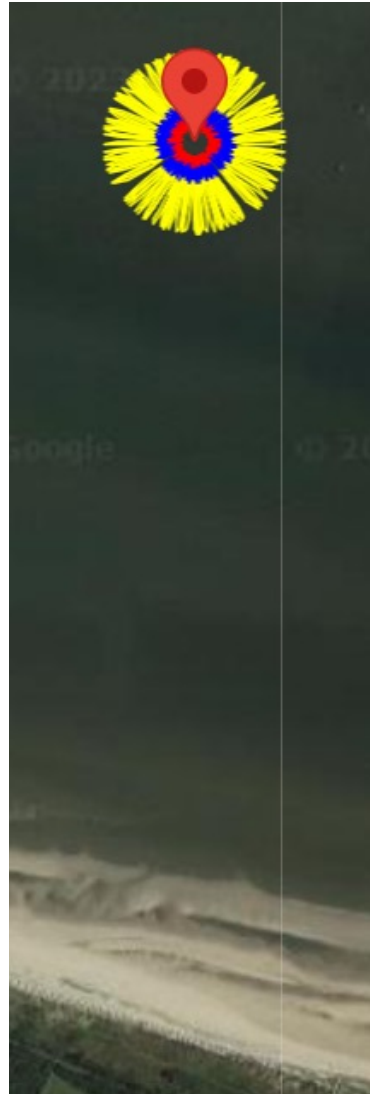


# GNSS-IR WATER LEVELS : SITE SELECTION/INSTALLATION



- Two classes here
  - your own installation (4<sup>th</sup> day of class) 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
- Like snow depth 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

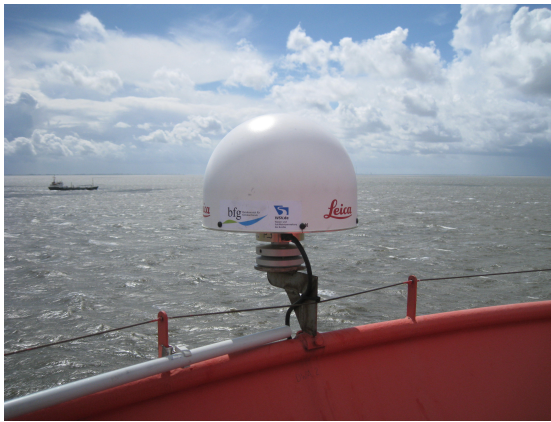
# GNSS-IR WATER LEVELS : “PERFECT” SITE (THEORETICALLY)



- 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

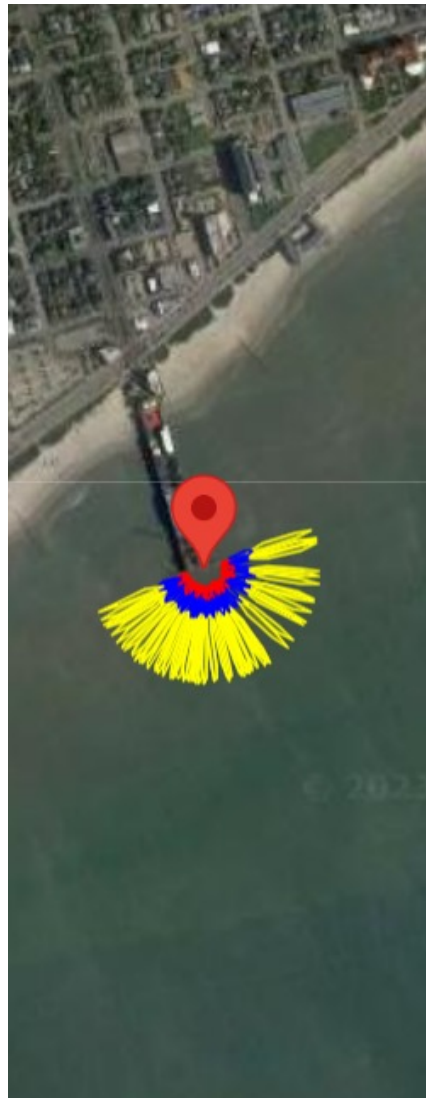


# GNSS-IR WATER LEVELS : “NOT SO PERFECT” SITE



- 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

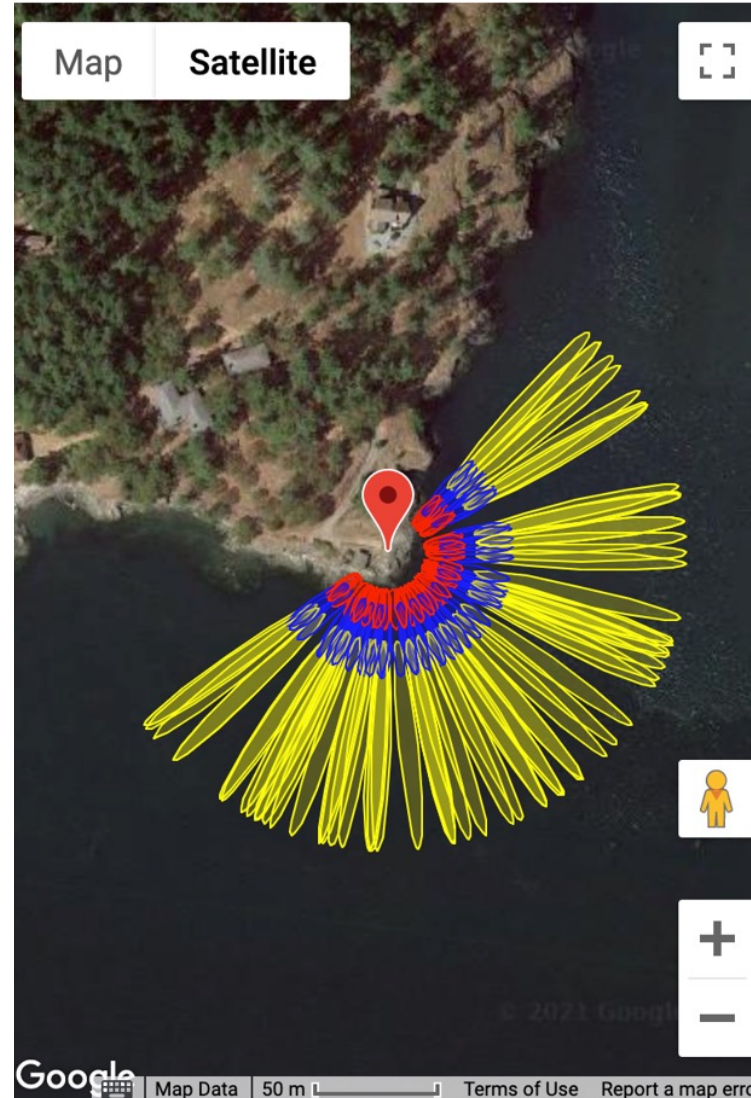
# GNSS-IR WATER LEVELS : LAND SITES



- 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.



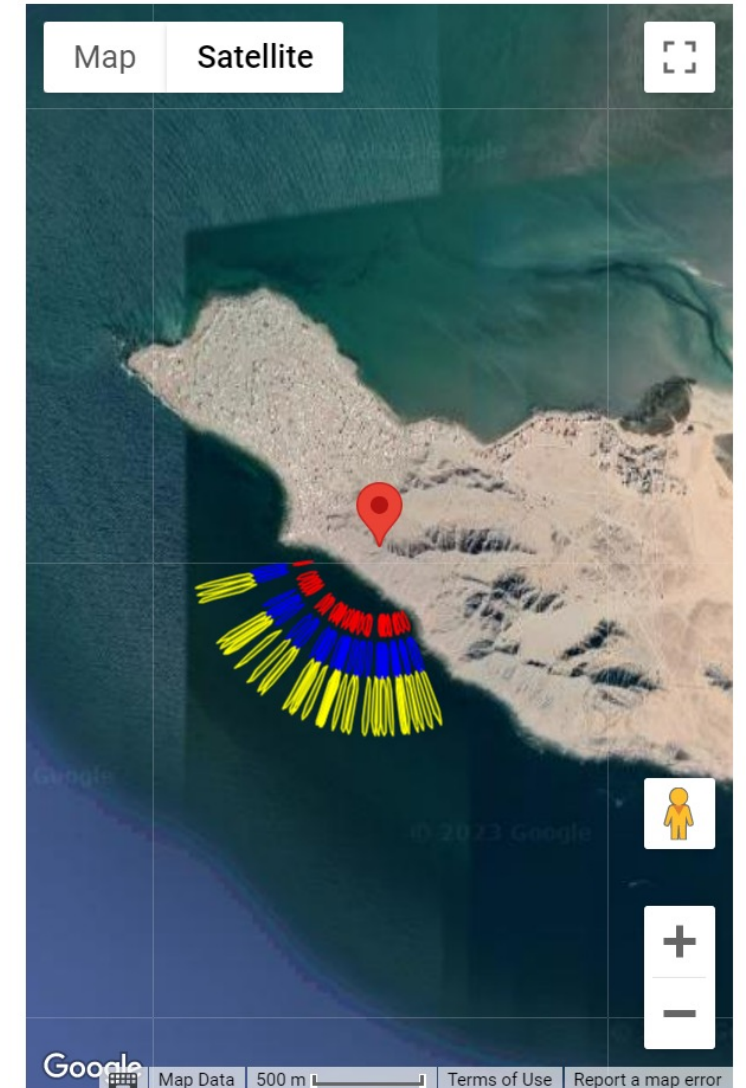
# GNSS-IR WATER LEVELS : MORE CHALLENGING SITE

- 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](#)



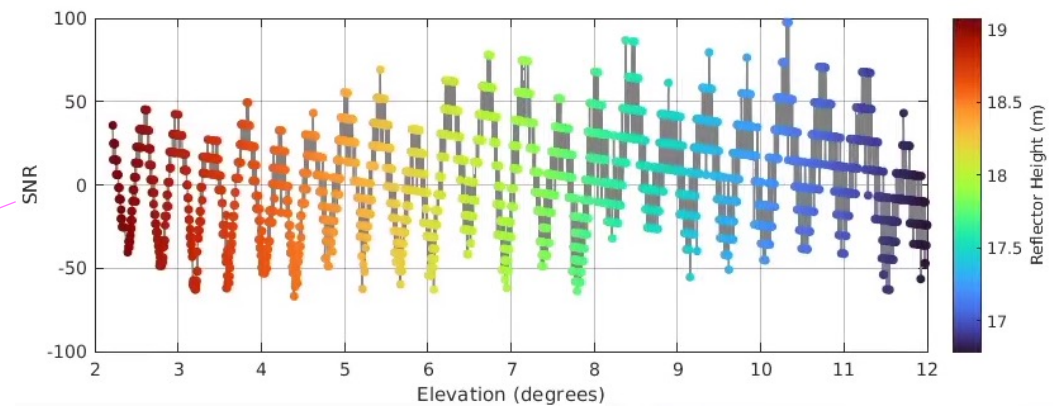
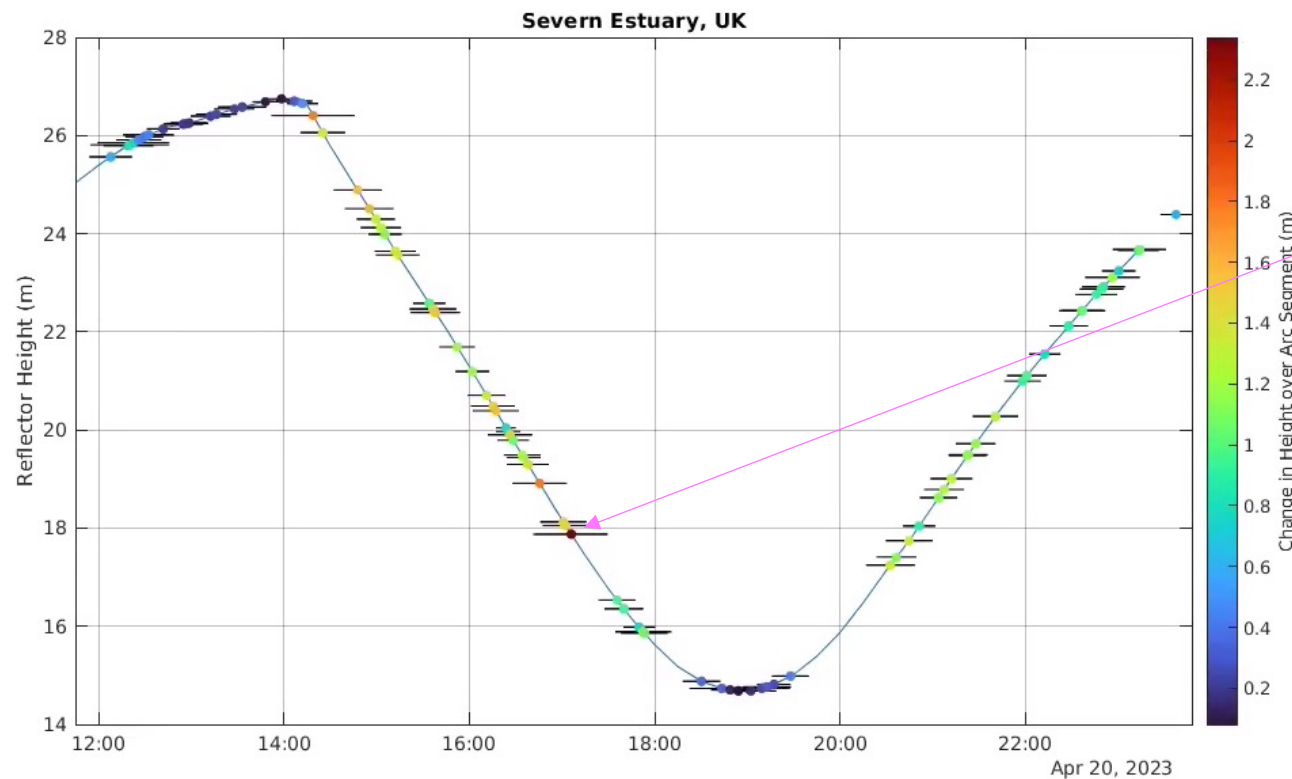


# GNSS-IR WATER LEVELS : VERY CHALLENGING SITES



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

- 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



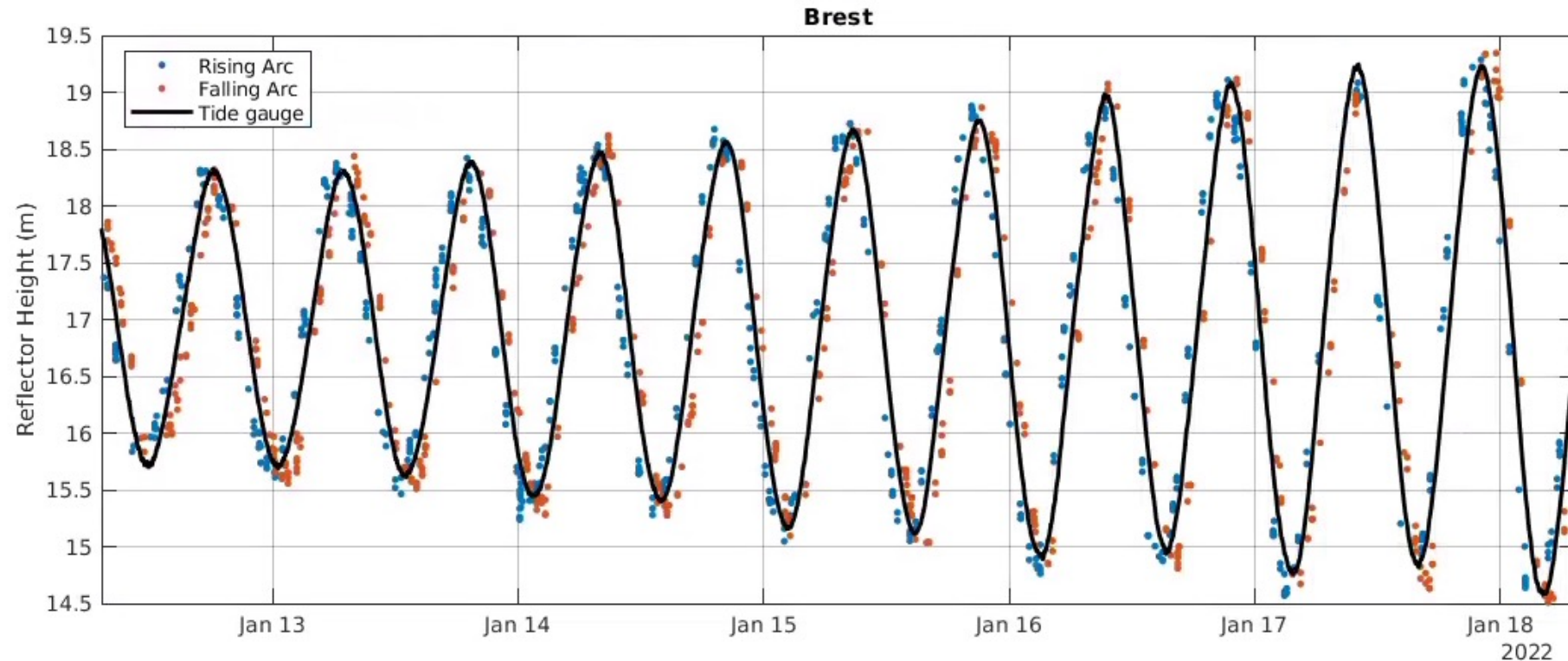


# GNSS-IR WATER LEVEL : TIME VARYING SURFACE ( $\dot{h}$ ) EFFECT

- 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



- 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

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

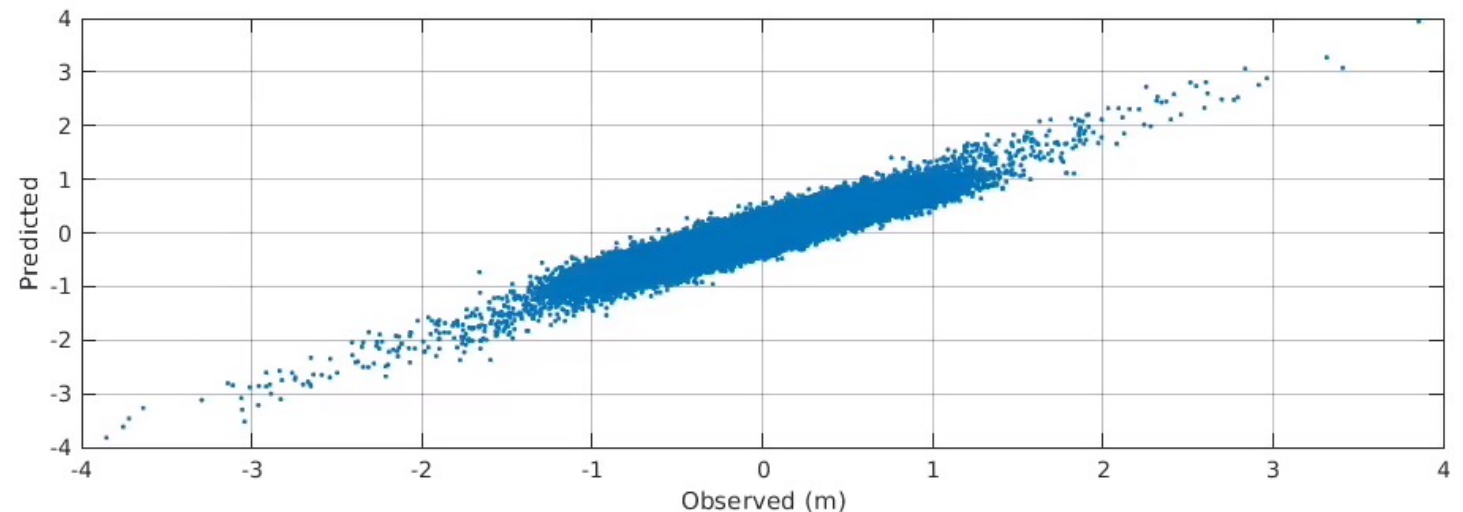
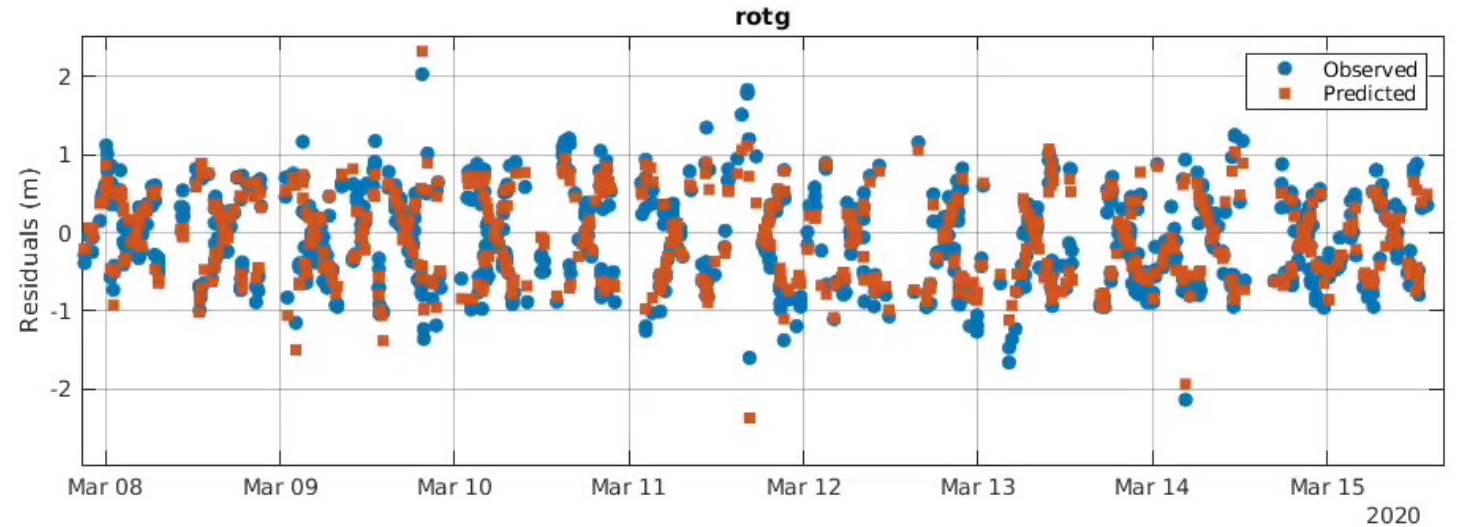
So how do you account for the  $\dot{h}$  effect?

Process as normal and then fit a curve to the results and then take its gradient and

$$\text{calculate } \frac{\dot{h} \tan \varepsilon}{\dot{\varepsilon}}$$

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

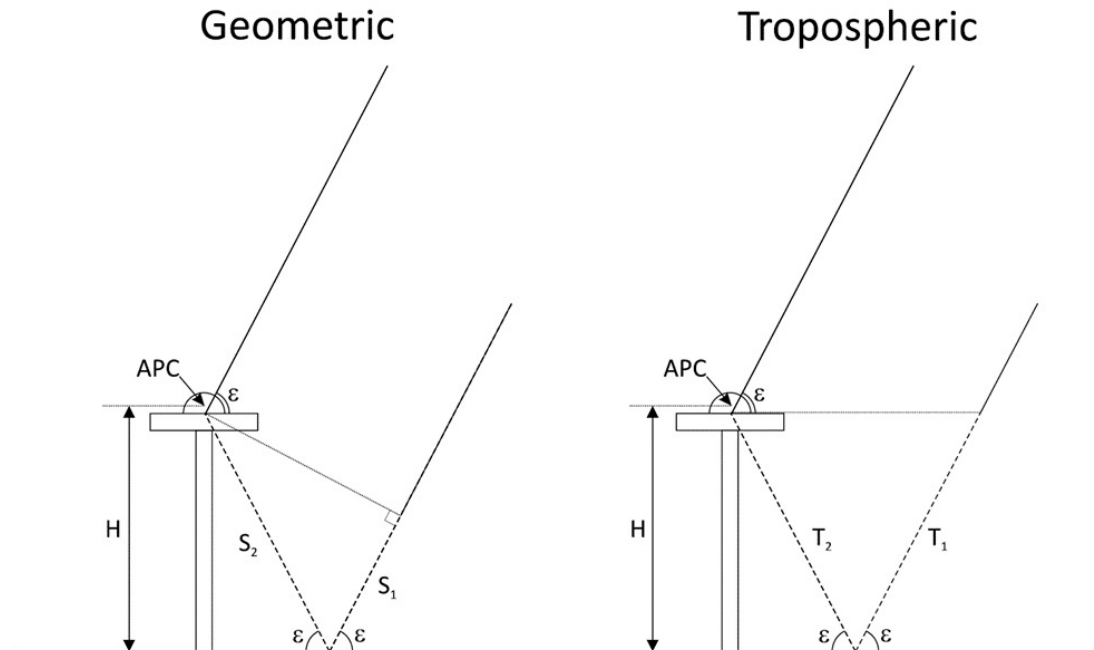
Beware of using long arcs!





# 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



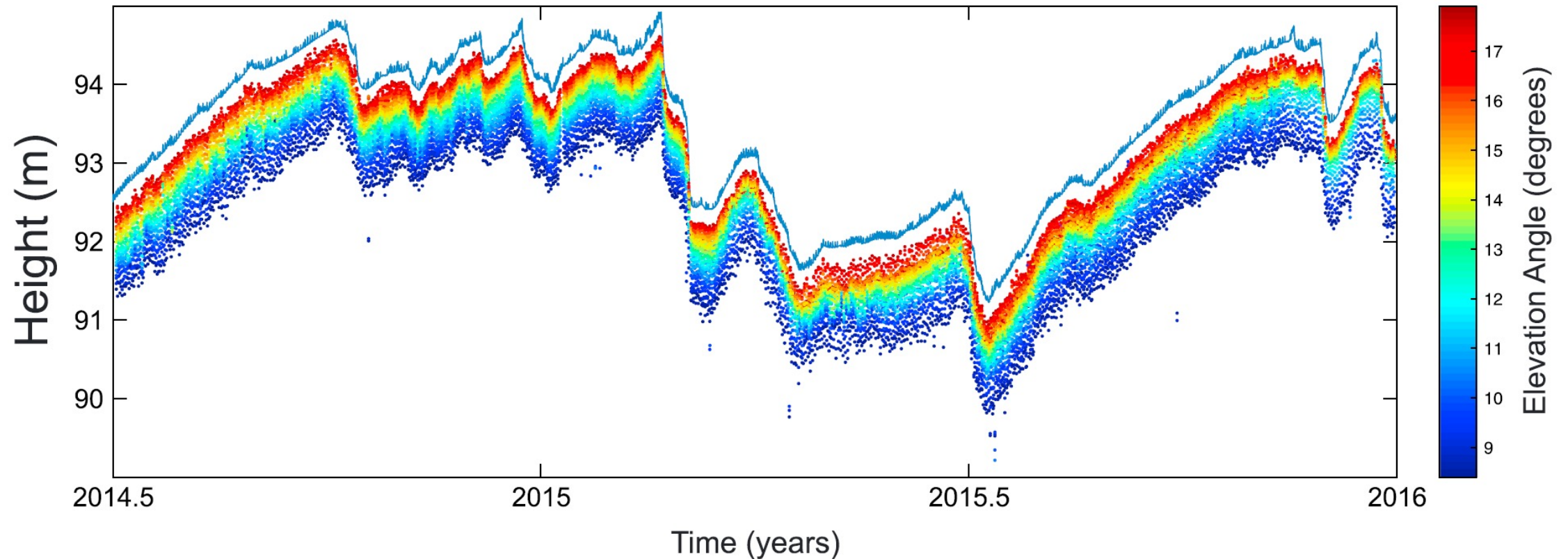
# GNSS-IR WATER LEVEL : TROPOSPHERIC DELAY

- 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  $f = \frac{2}{\lambda} \left( h + \frac{1}{2} \frac{\delta \tau_T}{\delta \sin \epsilon} \right)$
- 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

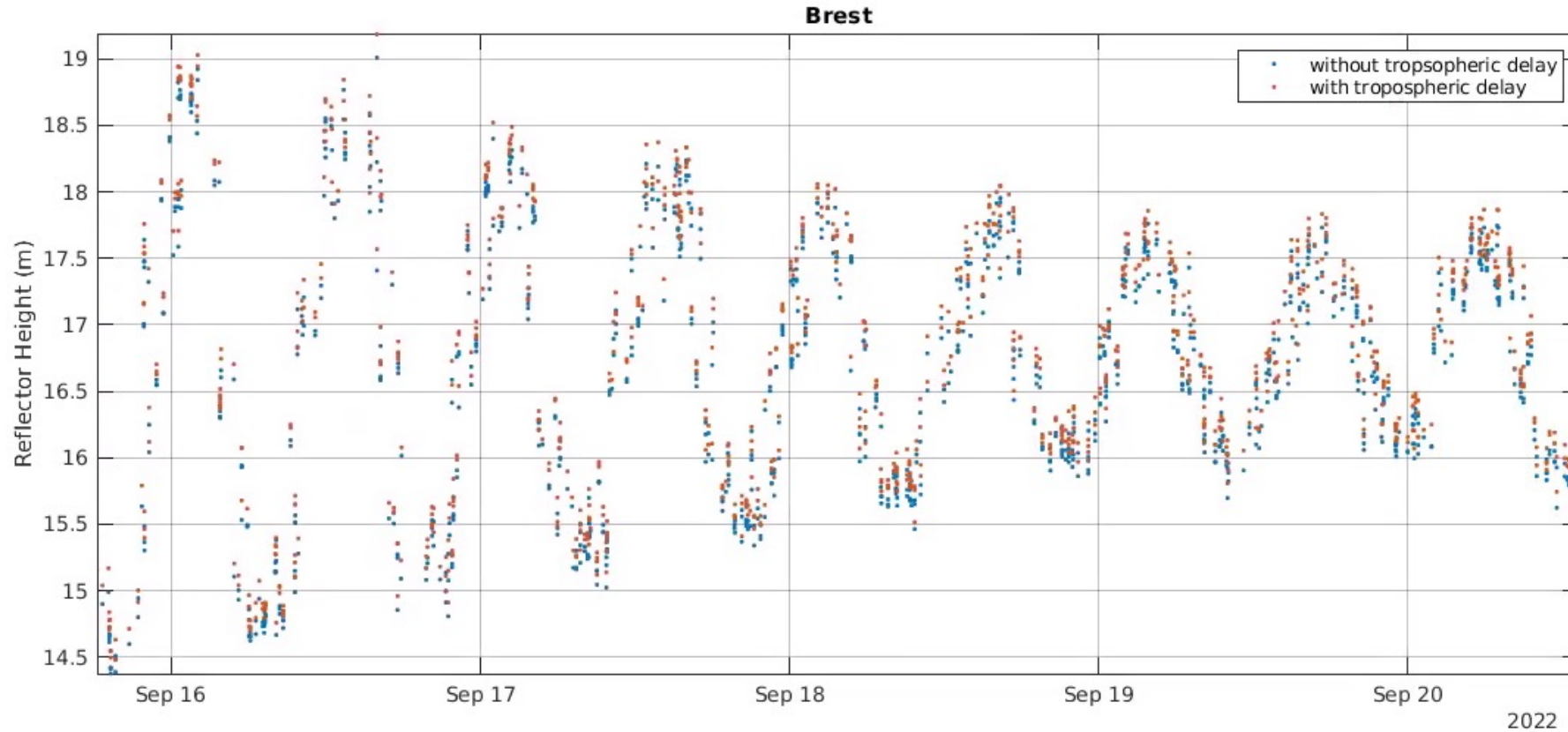
KYDH : Dale Hollow Lake, Kentucky Antenna 90+ m above lake

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



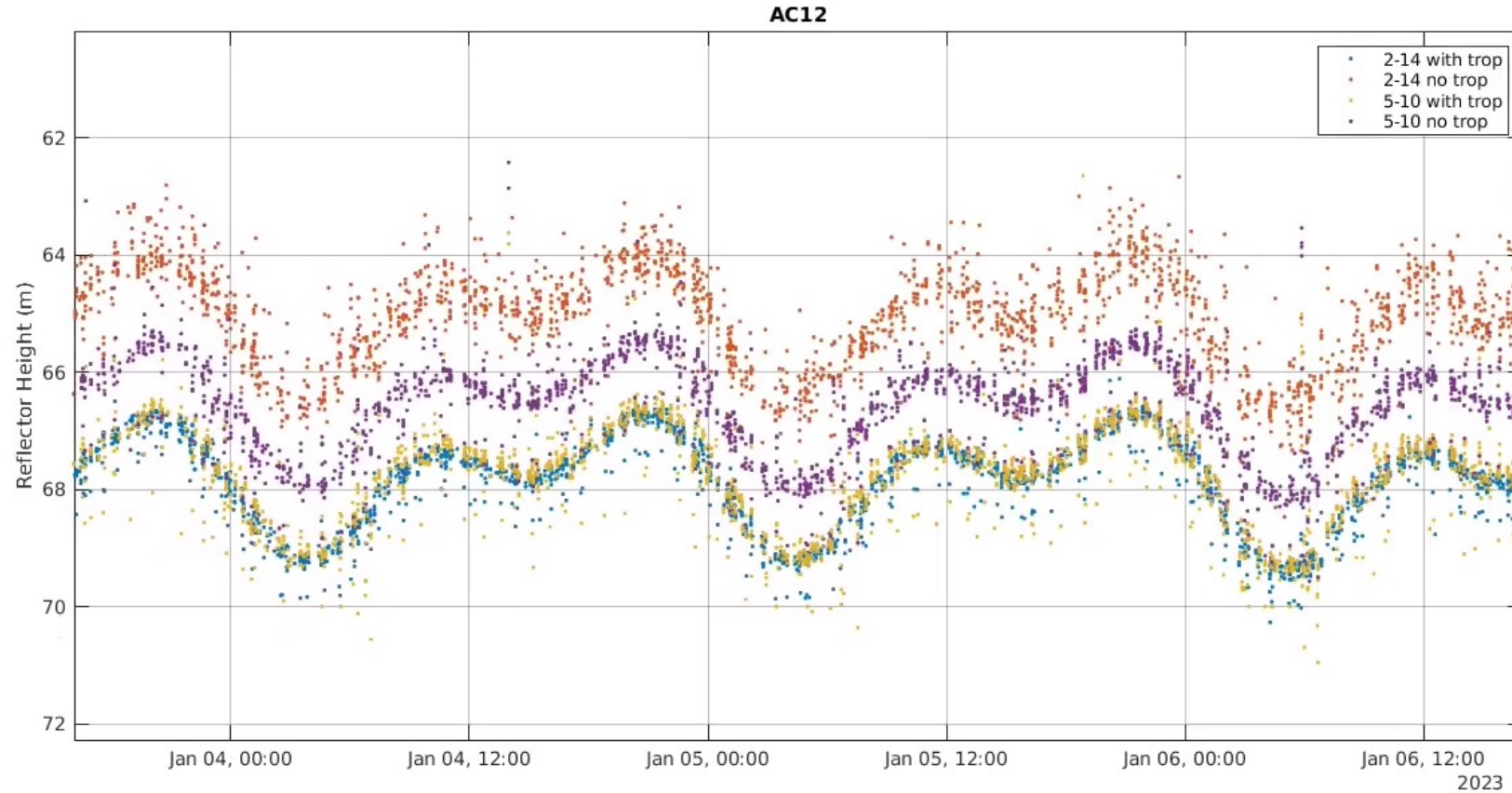


# GNSS-IR WATER LEVEL : TROPOSPHERIC DELAY



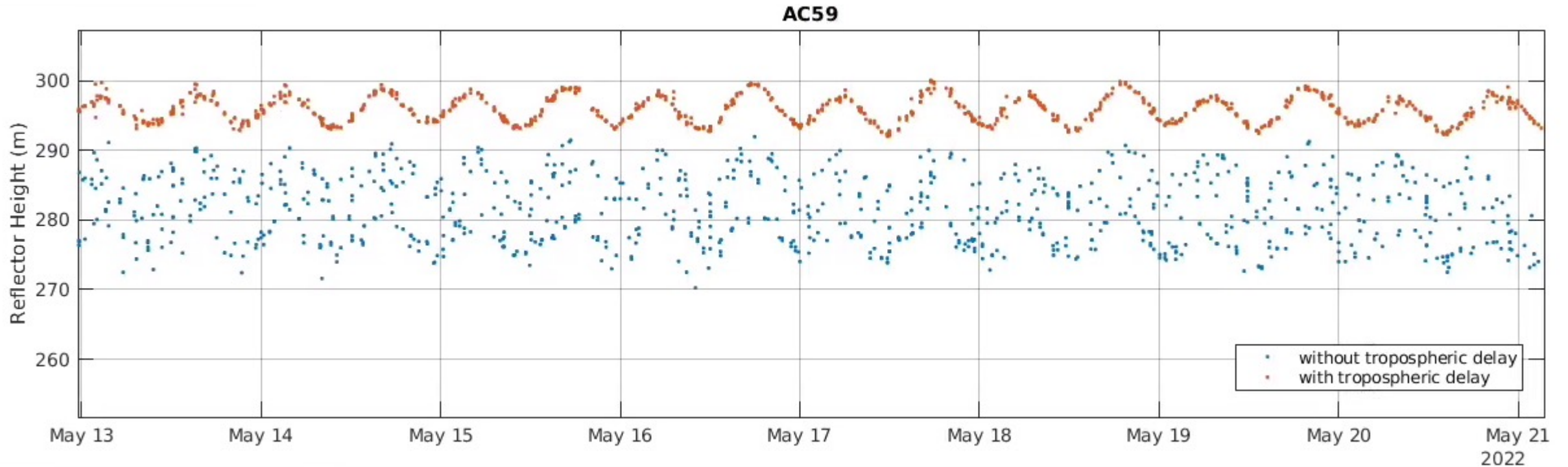
For a site like Brest, 17 m above the water you can just see an offset in the results with/without tropospheric delay applied. The median difference is 11.5 cm

# 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

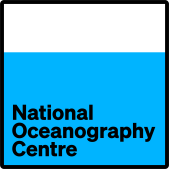
# GNSS-IR WATER LEVEL : TROPOSPHERIC DELAY



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

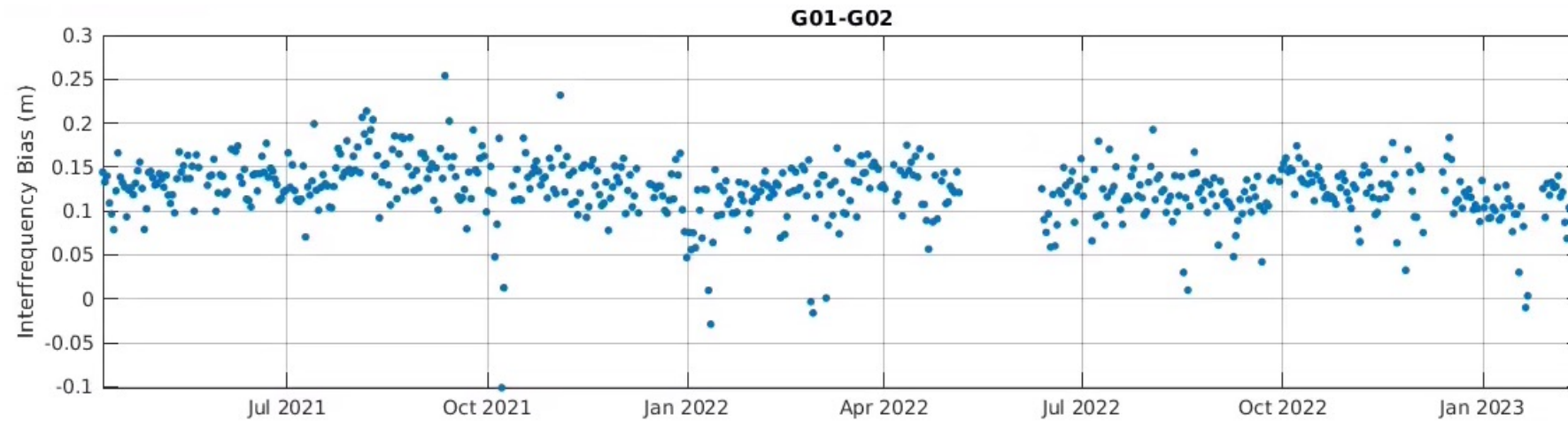
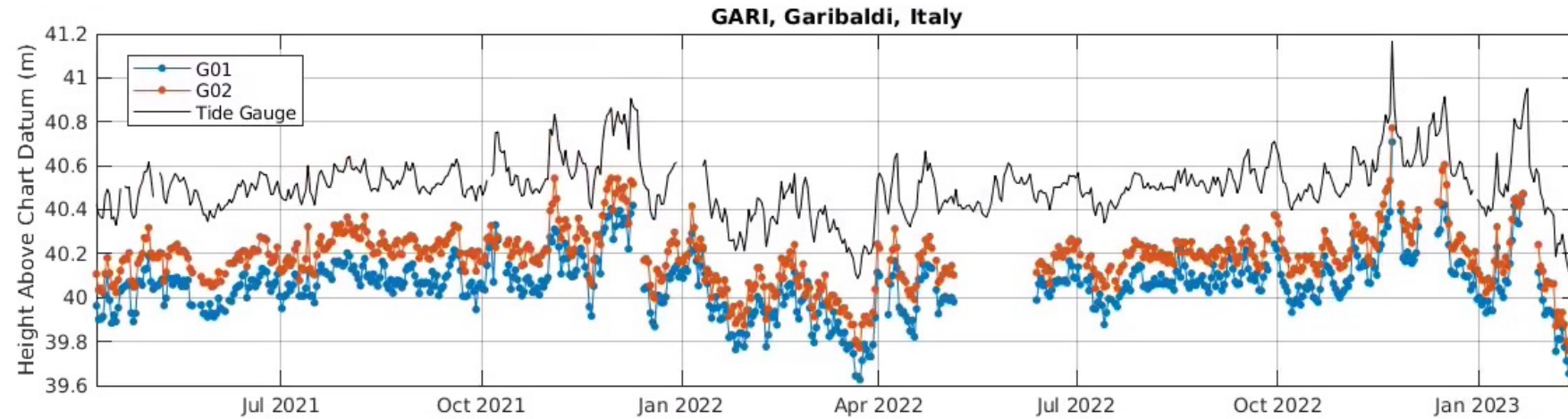


# GNSS-IR WATER LEVEL : INTER-FREQUENCY BIAS

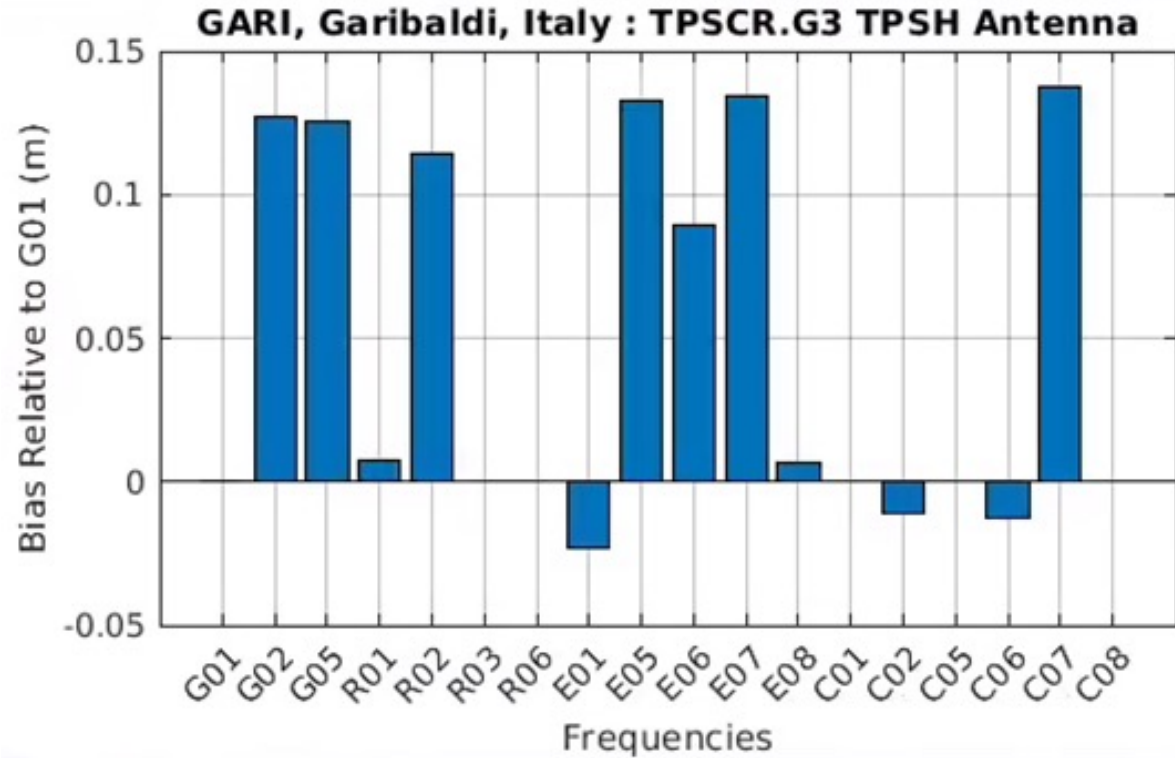


- In GNSS processing it is well known that the estimated position are related to what is known as the antenna phase centre (APC) (not a physical point)
- The APC is different for different frequencies
- The GNSS community uses special techniques to measure the APC for all major antennas
- In GNSS-IR 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

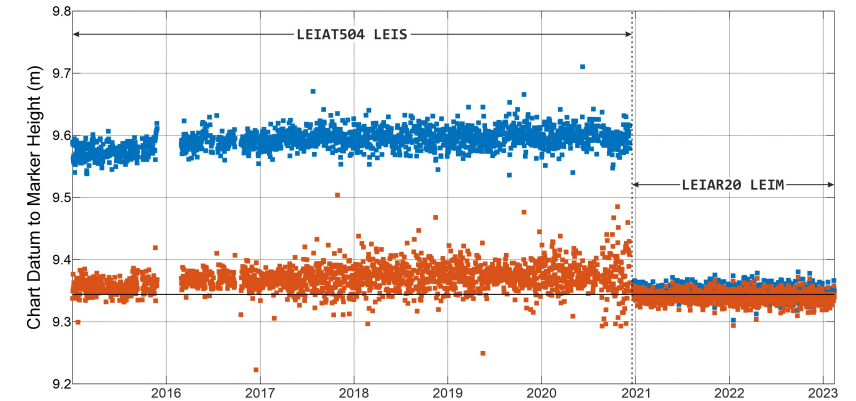
# GNSS-IR WATER LEVEL : INTER-FREQUENCY BIAS



# GNSS-IR WATER LEVEL : INTER-FREQUENCY BIAS



- Note the interfrequency bias is different for different antennas



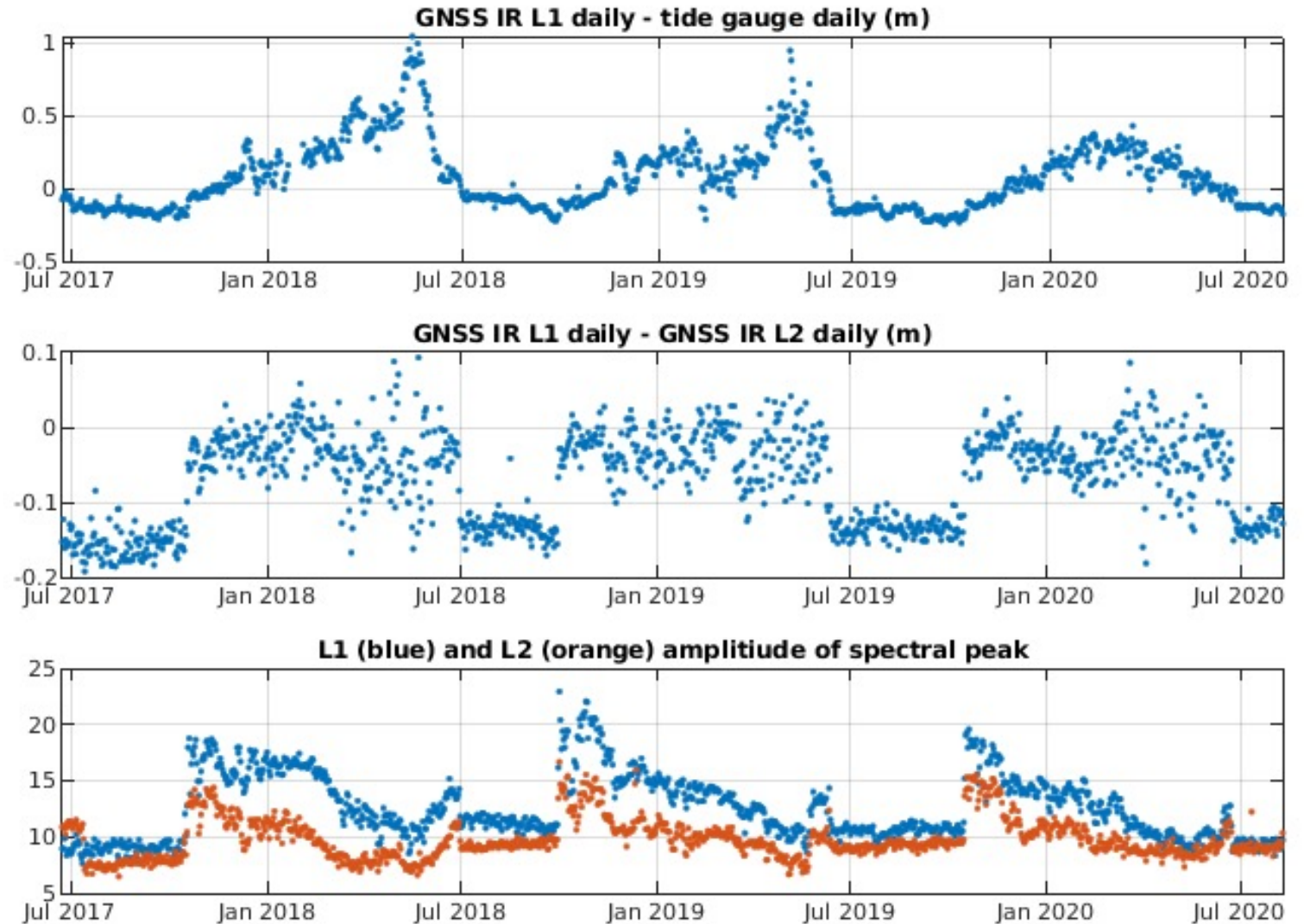
Blue is G01  
Orange is G02

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

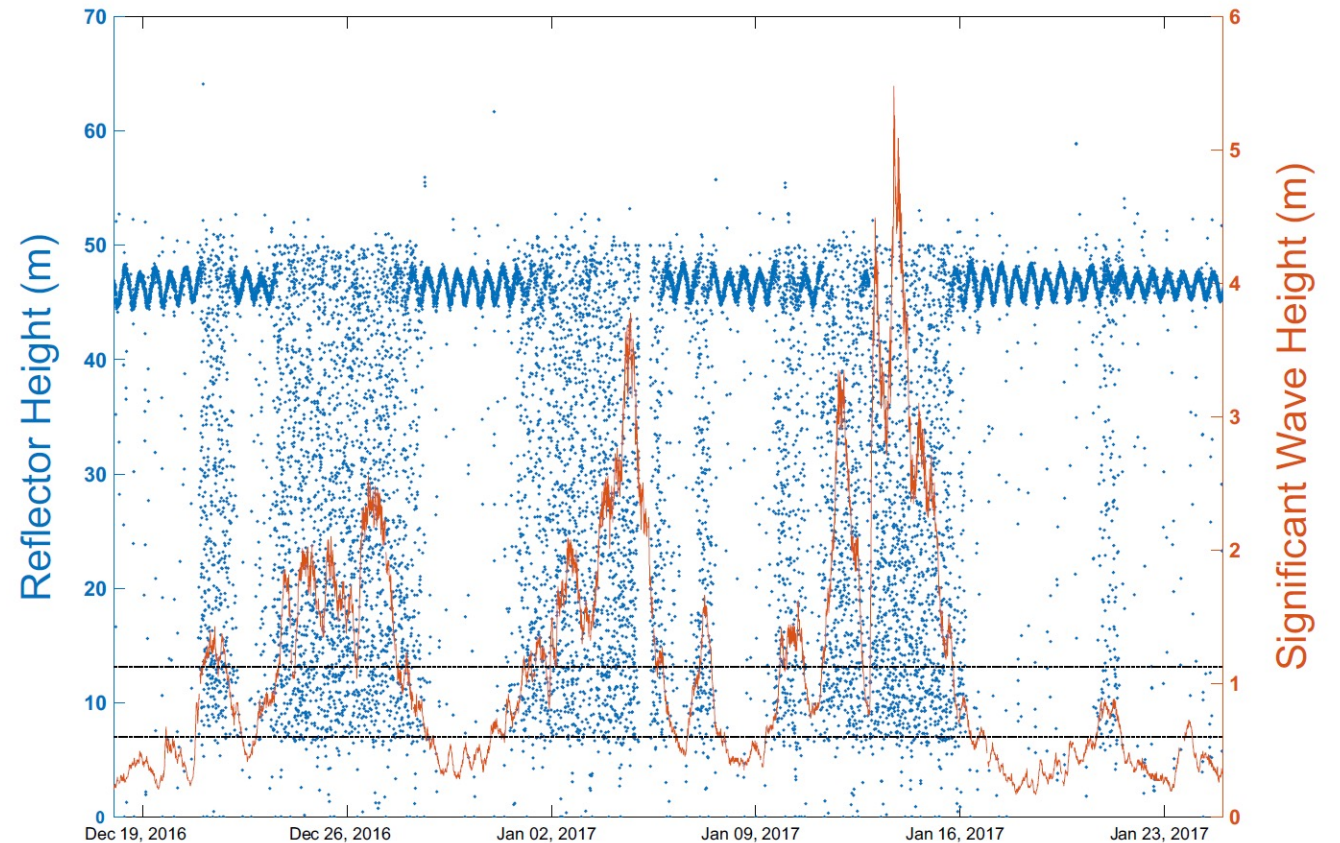


# GNSS-IR WATER LEVEL : EFFECT OF WIND/WAVES

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



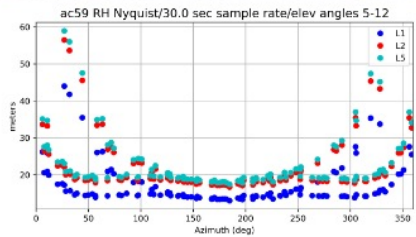
## BLIGH BANK II Windfarm Substation South West North Sea



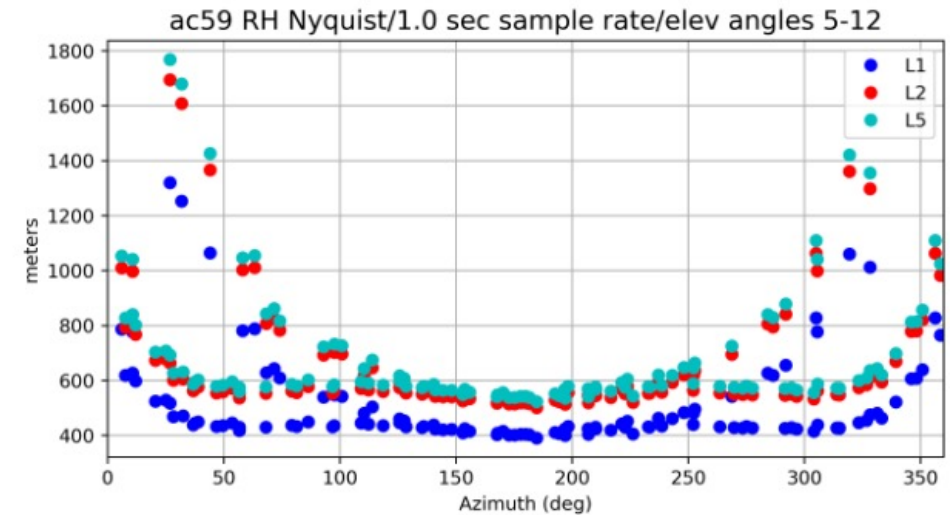
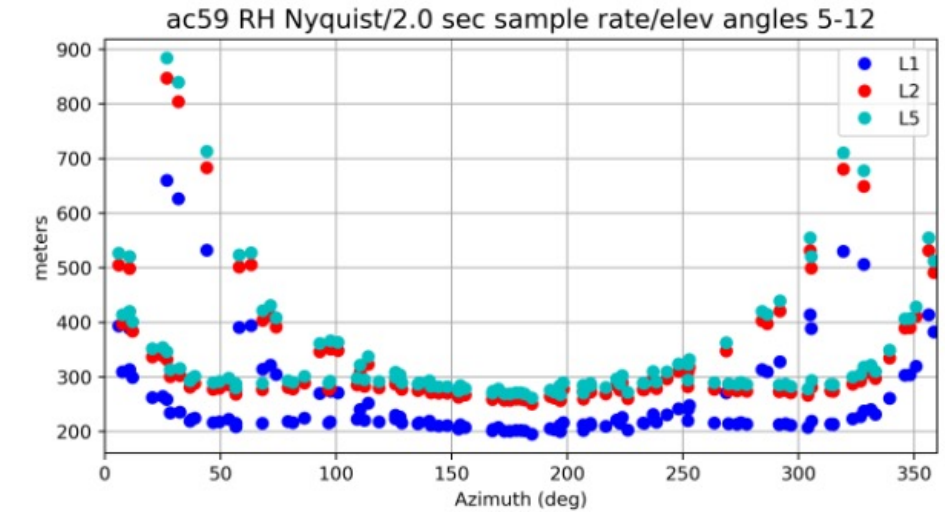
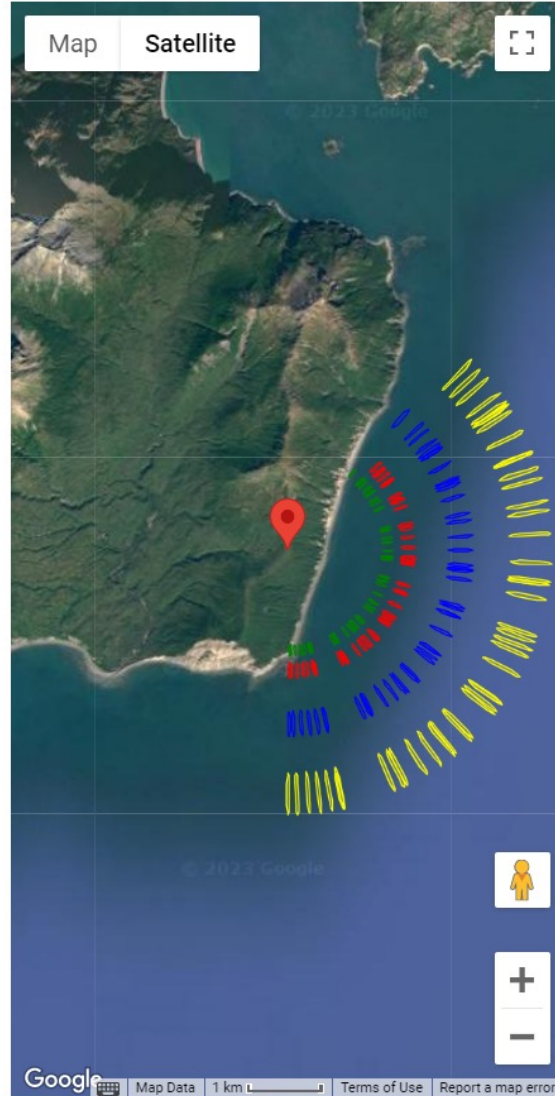


# NYQUIST LIMIT

**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



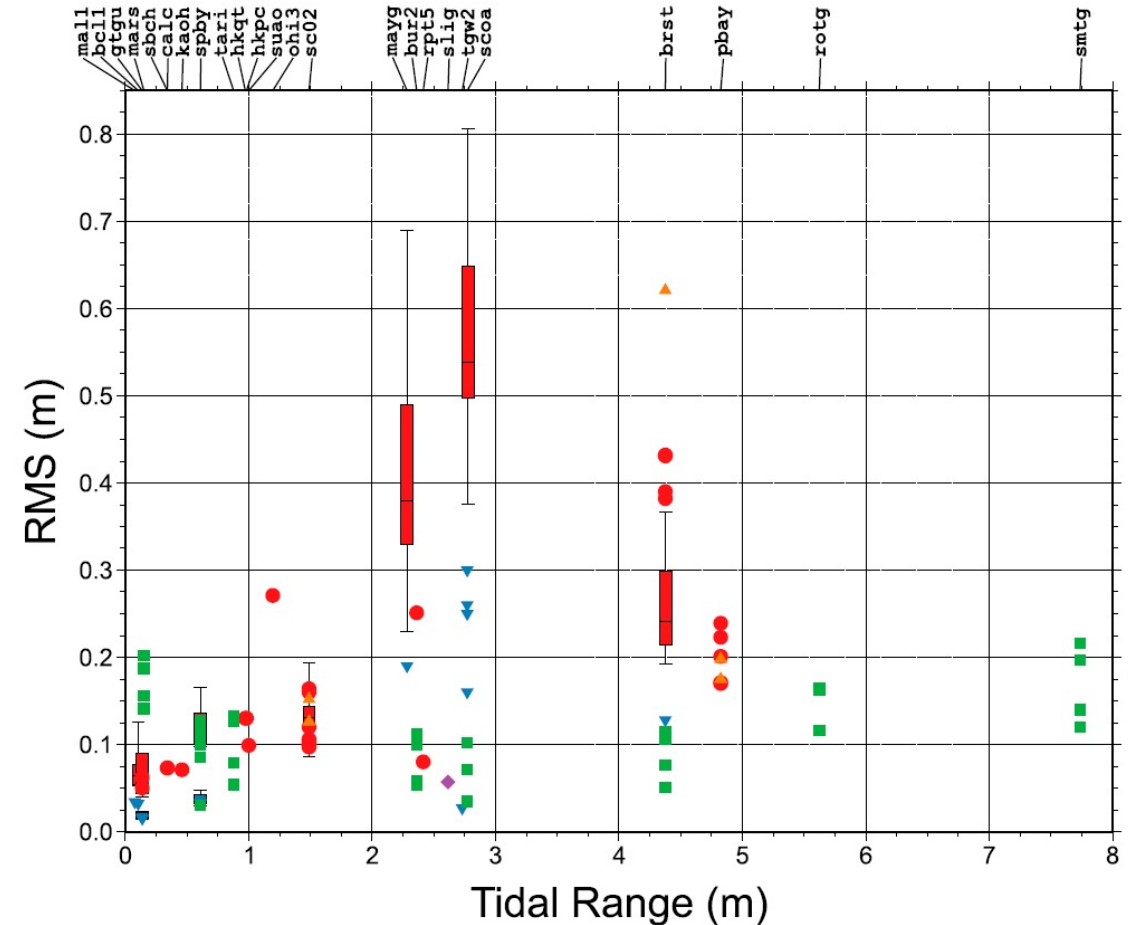
[Return to the Reflection Zone API](#)





# 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



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