National Oceanography Centre

Permanent Service for Mean Sea Level

A NEW DATASET OF RELATIVE SEA LEVEL MEASUREMENTS CREATED USING GLOBAL NAVIGATION SATELLITE SYSTEM (GNSS) RECEIVERS

Andrew Matthews, Simon Williams, Chris Banks

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WHAT IS THE PSMSL?
(PERMANENT SERVICE FOR MEAN SEA LEVEL)

THE GLOBAL TIDE GAUGE NETWORK AT PSMSL.ORG

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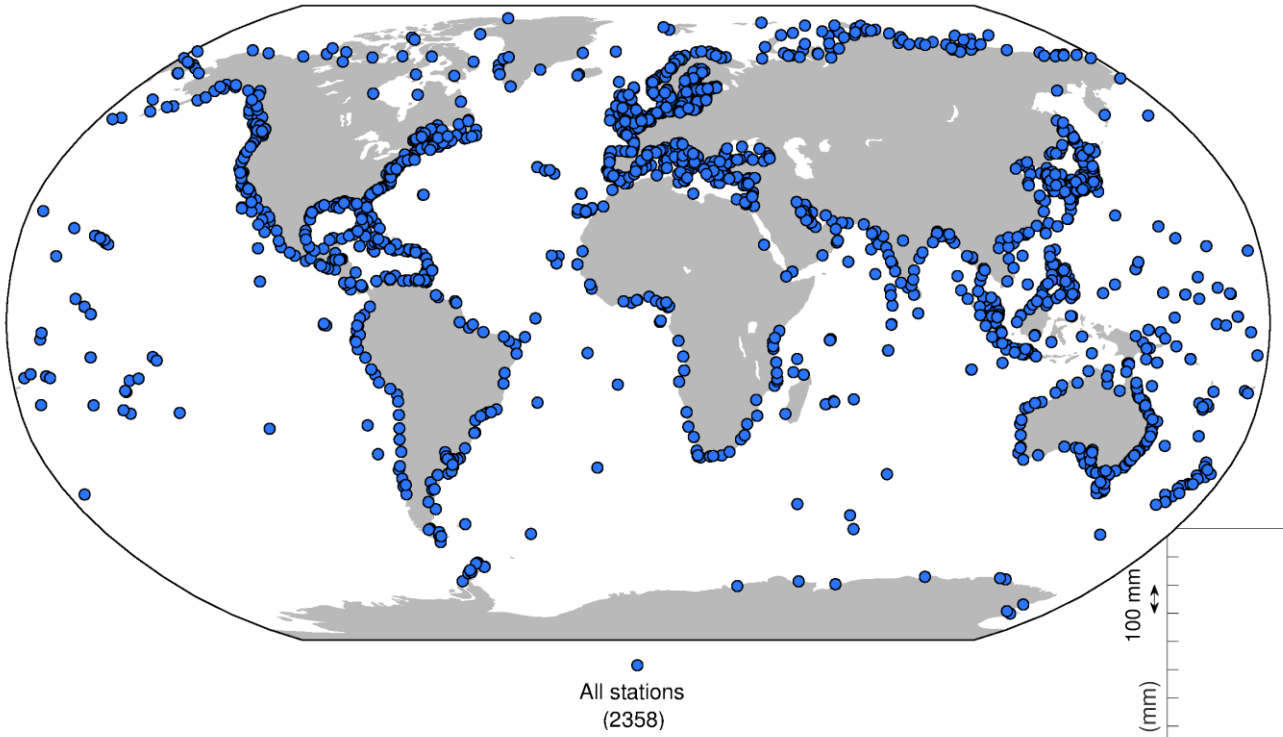
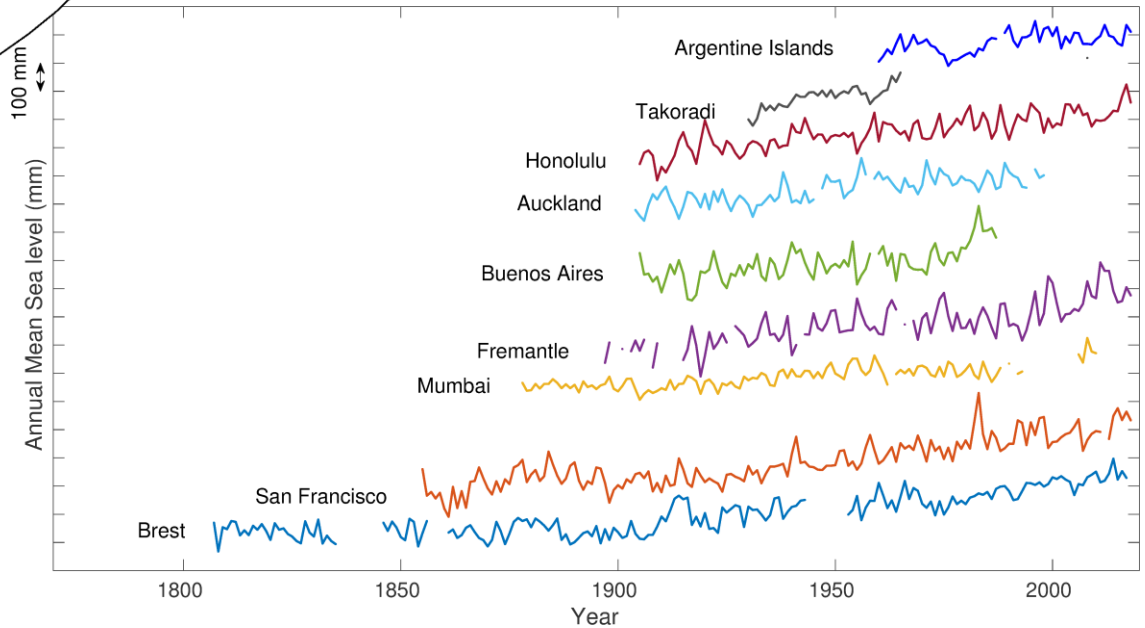


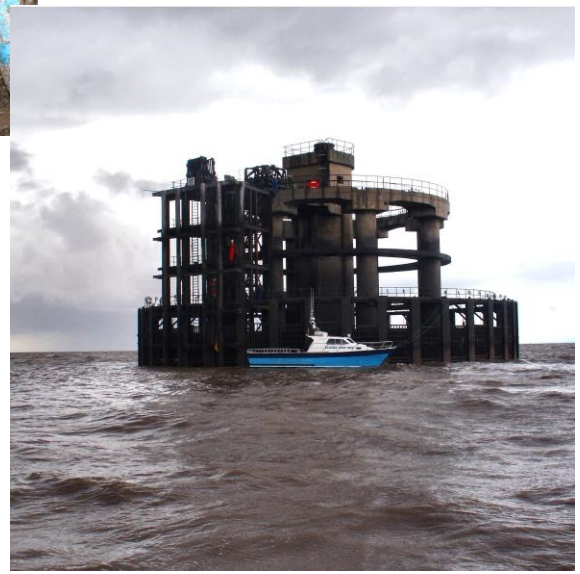
The PSMSL is a global databank for mean sea level data measured at tide gauges, and also provide advice on collection, distribution of sea level data.

PSMSL data forms the core of our understanding of sea level rise over the past couple of centuries, but is also used to study ocean currents vertical and land movement.



The global tide gauge network continues to improve, but gaps still exist, particularly in the Southern Hemisphere. Furthermore, funding issues mean that the quality of data from long running records is under threat.

WHY AREN'T THERE MORE TIDE GAUGES?



While tide gauge sensors themselves are not very expensive, there are considerable costs involved in operating them over a long period of time, particularly when budgets are tight:

- Water based sensors (e.g. pressure transducers) suffer from biofouling, and can require divers to perform maintenance.
- Land based sensors (e.g. radar or acoustic) are exposed to damage from storms, vandalism, or general accident in often busy port environments.
- Gauges can be located in remote, hard to access areas

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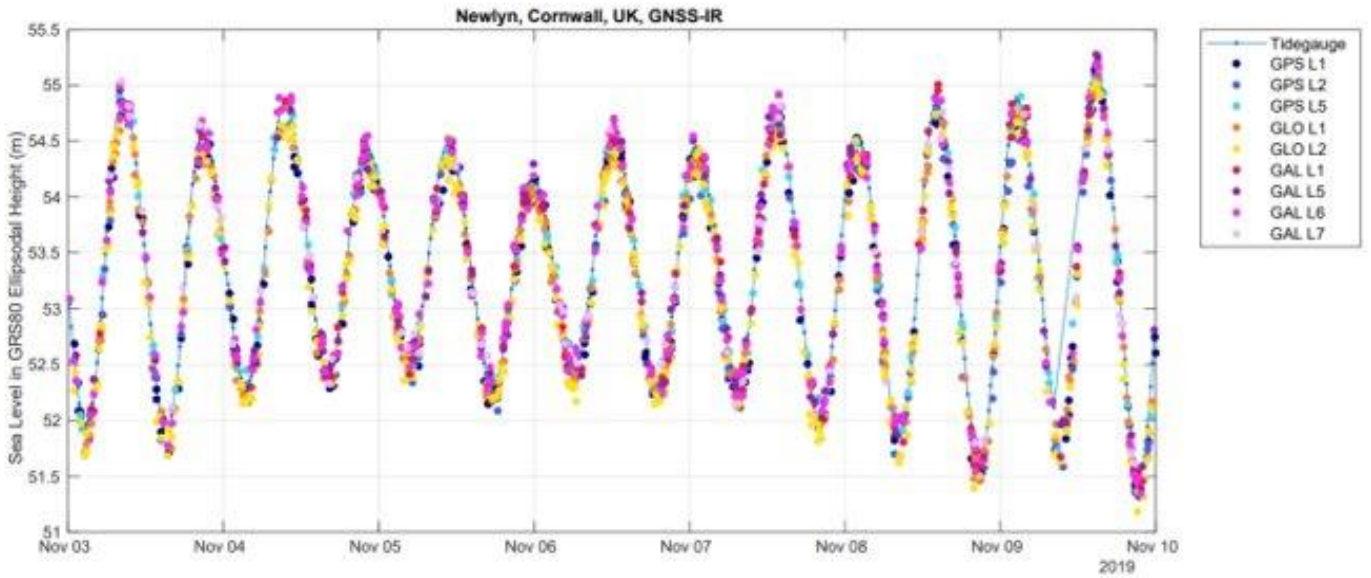
WHAT IS GNSS INTERFEROMETRIC REFLECTOMETRY? (GNSS-IR)

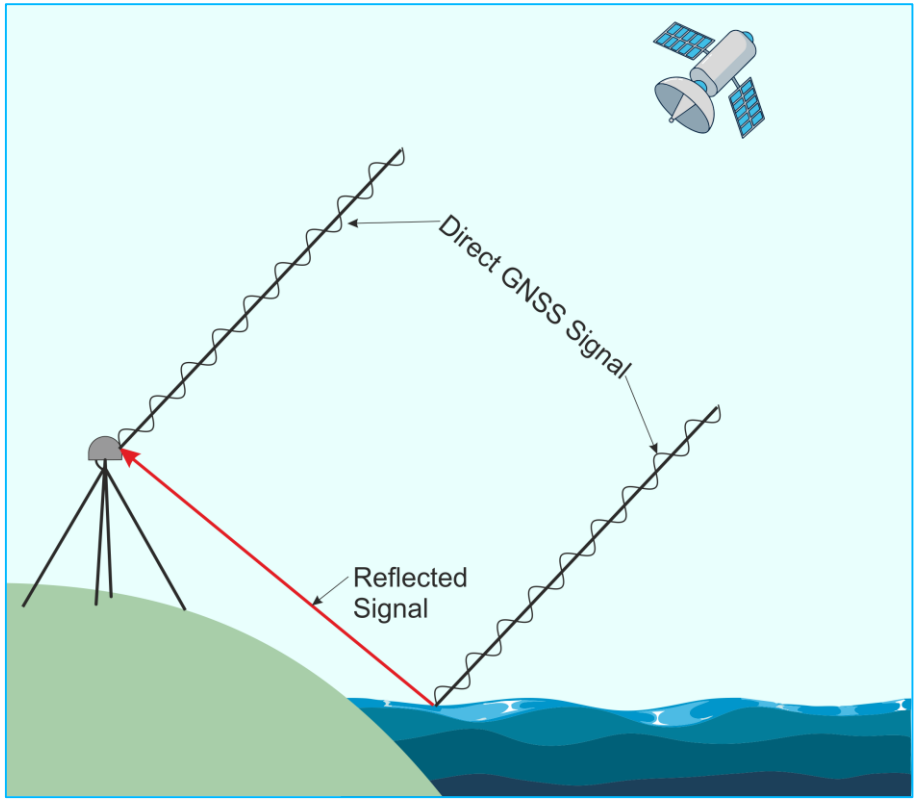
GNSS INTERFEROMETRIC REFLECTOMETRY (GNSS-IR)



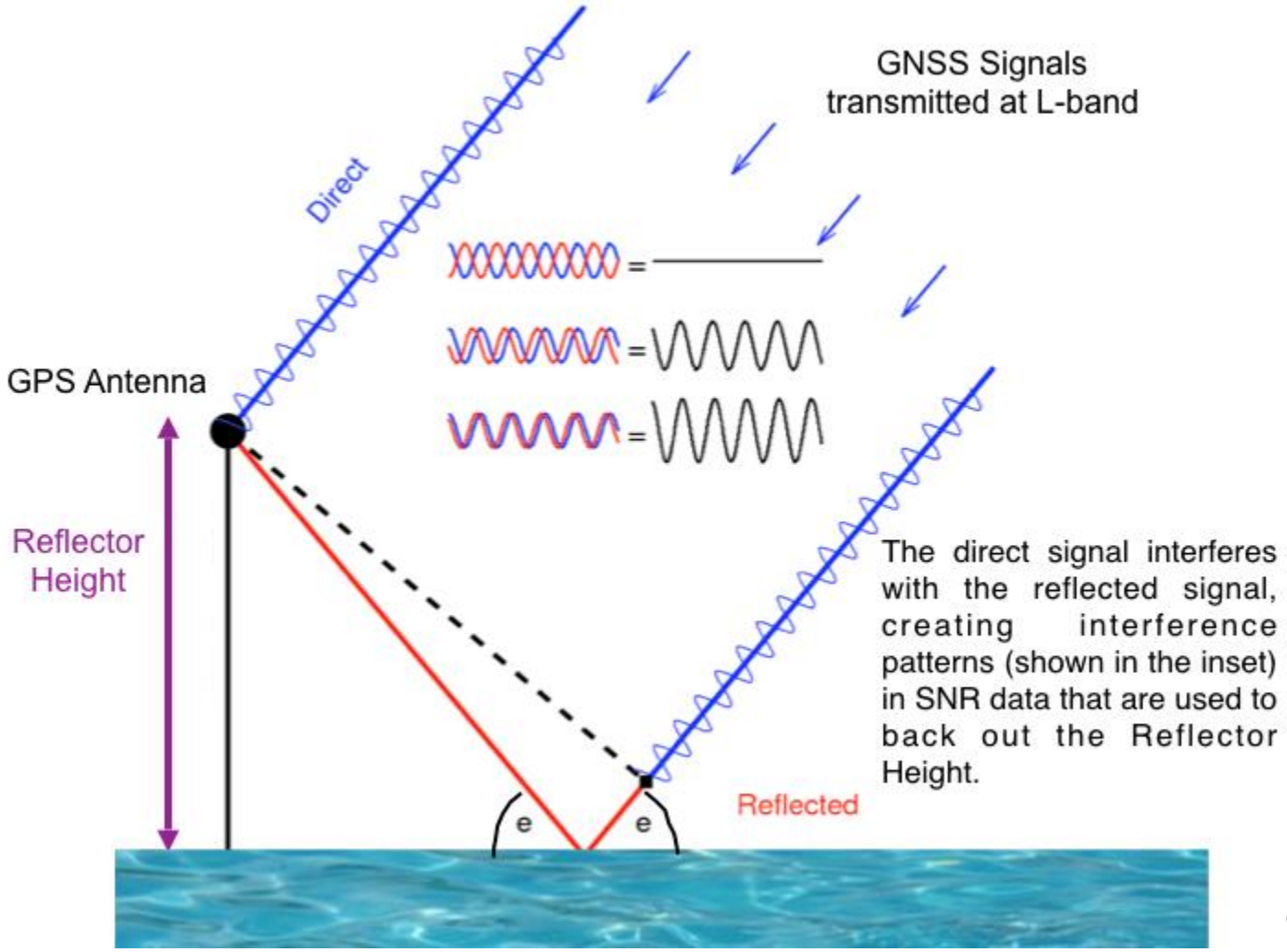
This technique allows sea level to be measured using only a GNSS receiver.

As well as a receiving a direct signal from a GNSS satellite, the GNSS receiver detects a reflected signal off the surface of the water. The phase delay between the direct and reflected signal will vary as the height of the water changes.

The emerging technology of GNSS-IR gives us the opportunity to measure sea levels without getting our feet wet

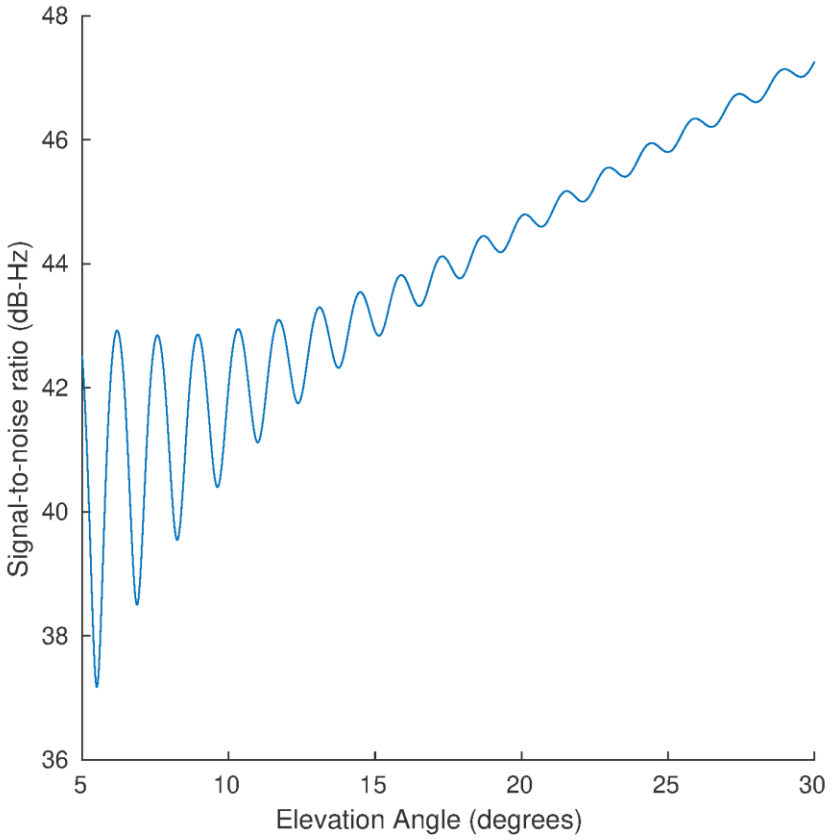


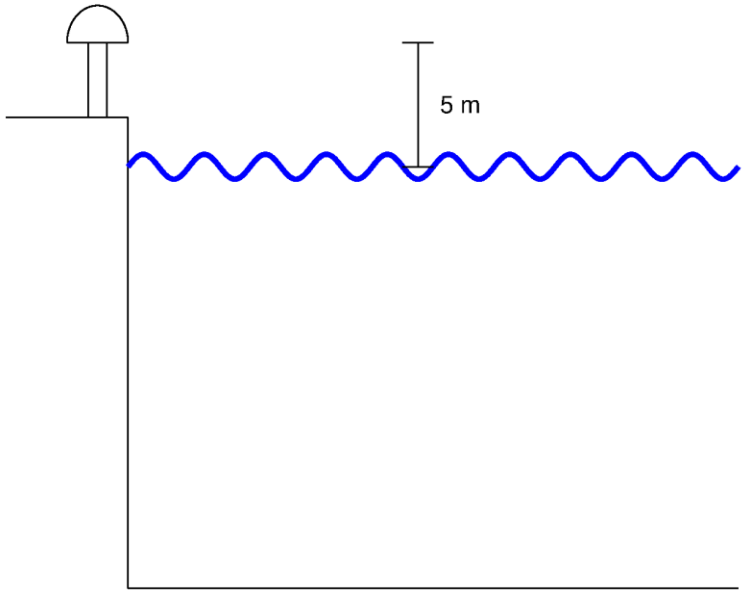
MEASURING SURFACES WITH GNSS-IR



Credit: Kristine Larson

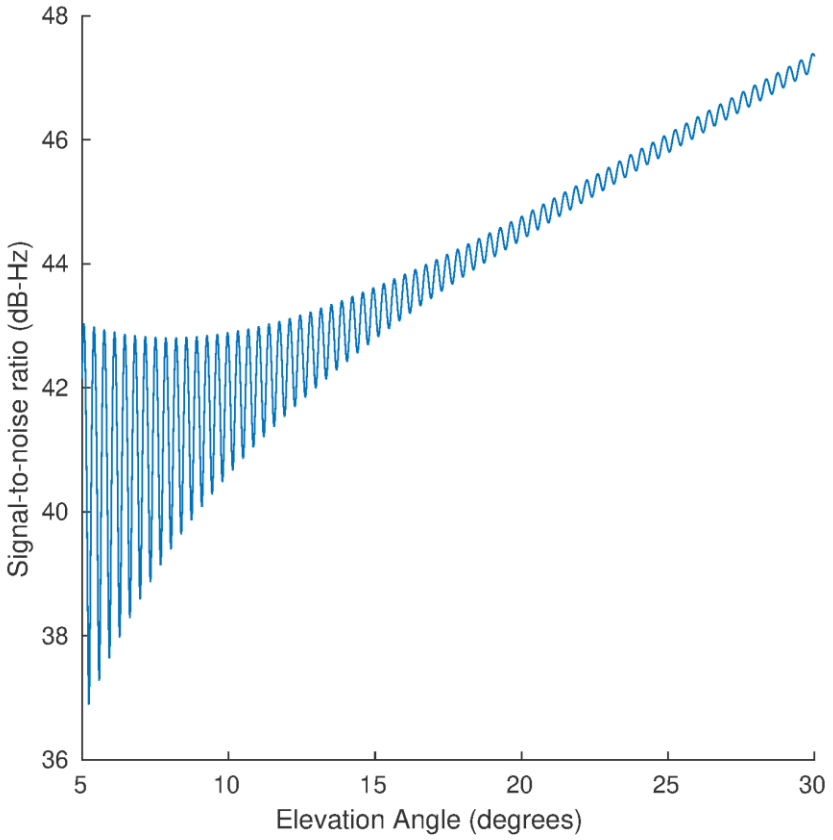
HOW SNR CHANGES WITH SEA LEVEL HEIGHT

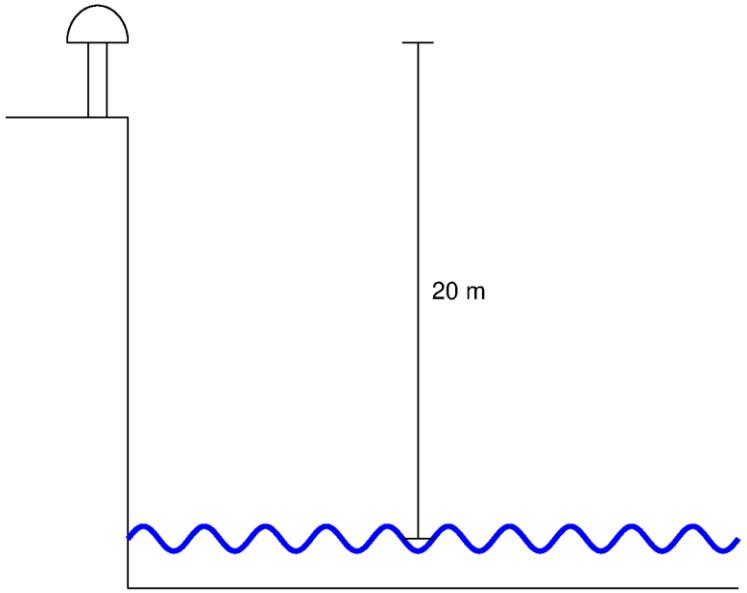




The plot of the signal-to-noise ratio as the GNSS satellite passes overhead changes as the height of the water changes. Lower water levels means the reflected signal has to travel further, resulting in greater frequency modulation. The water level can be extracted from this (see Larson et al., 2013)

HOW SNR CHANGES WITH SEA LEVEL HEIGHT





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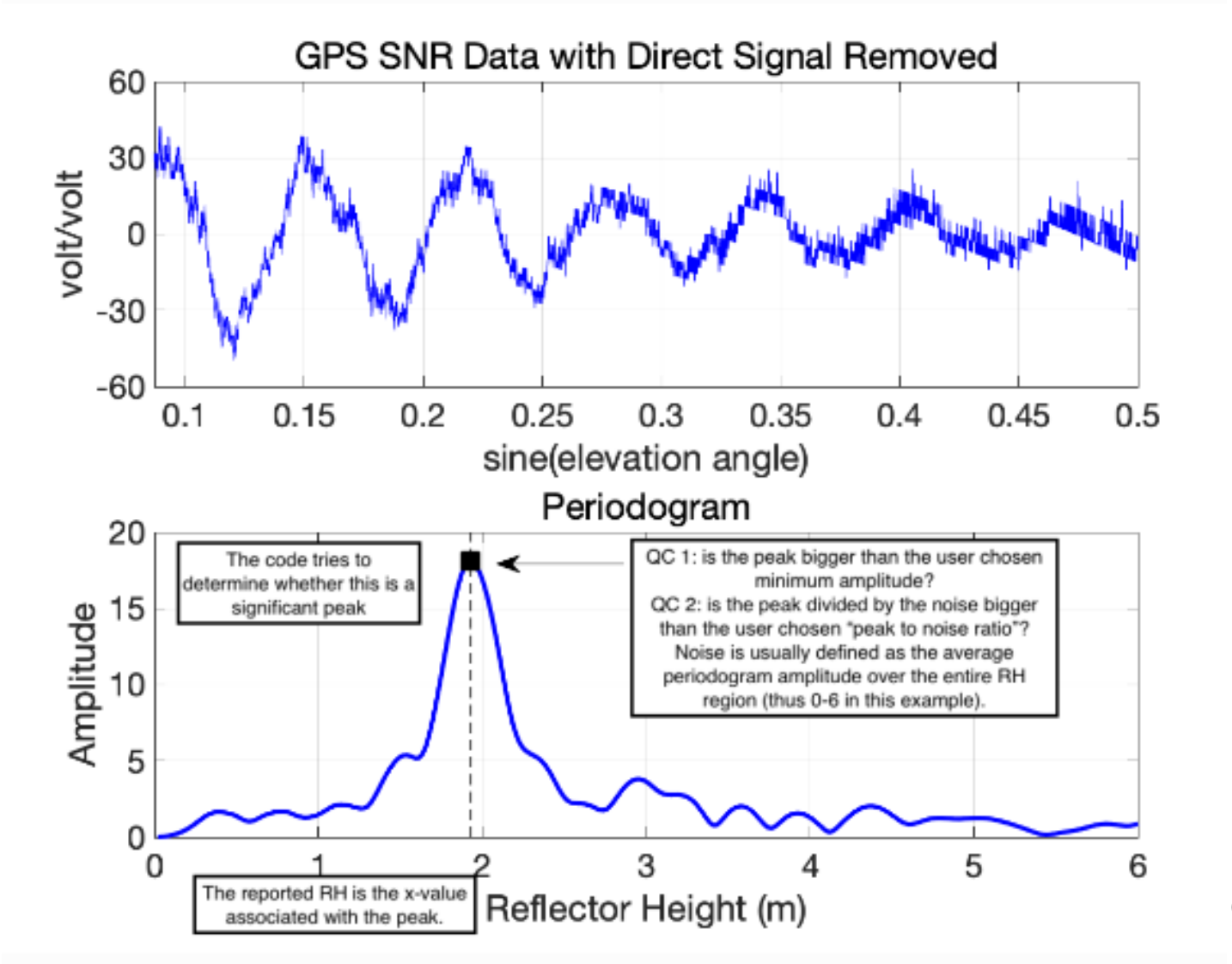
EXTRACTING THE SEA LEVEL FROM THE SNR



Credit: Kristine Larson

GNSS-REFLECTIONS.ORG

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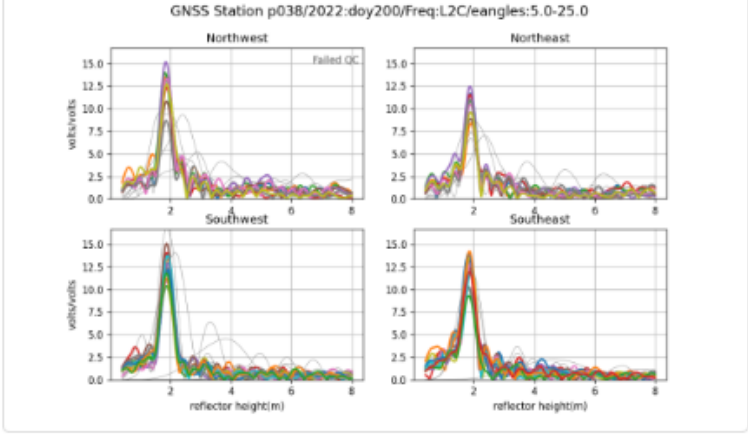
API for online processing of GNSS data

Python package hosted on GitHub

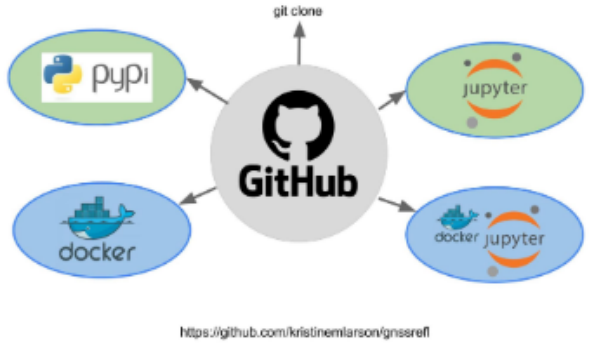
Tools for investigating satellite tracks above a site

GNSS Interferometric Reflectometry

GNSS-IR API



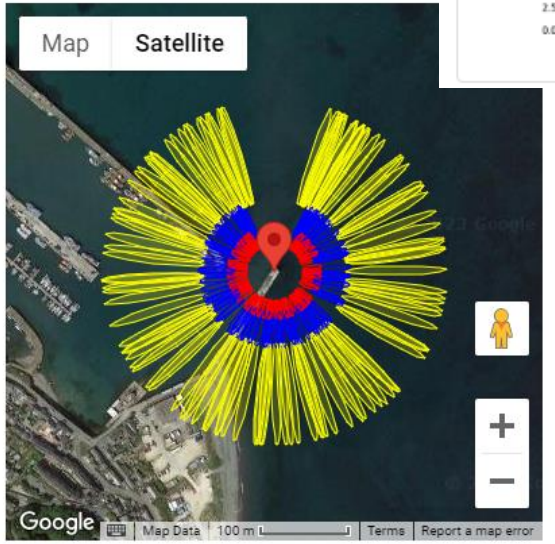
GitHub Repository



GNSS-IR Reflection Zone Mapping

Station: newl
Latitude: 50.10302834
Longitude: -5.54278961
Ellipsoidal Height(m): 64.502
Reflection Ht. (m) : 11.032
Elevation Angles (deg) : 5,10,15
Azimuth Angles (deg) : 0 to 360
Constellation : GPS
Frequency: L1

Return to the Reflection Zone API



Created by Kristine Larson

Tutorials & more on YouTube:
@funwithgps

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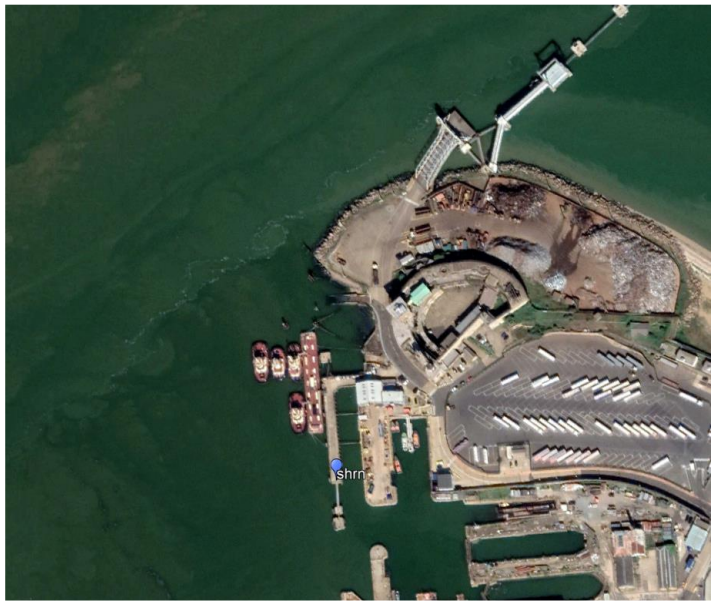
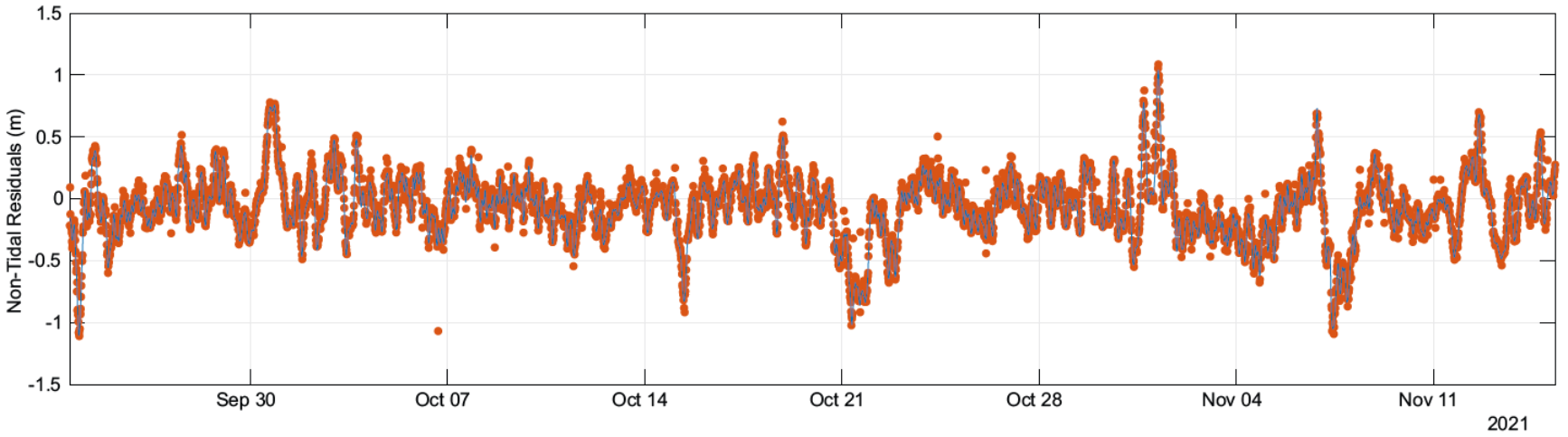
GNSS-IR IN PRACTICE

NOC INSTALLATIONS - SHEERNESS





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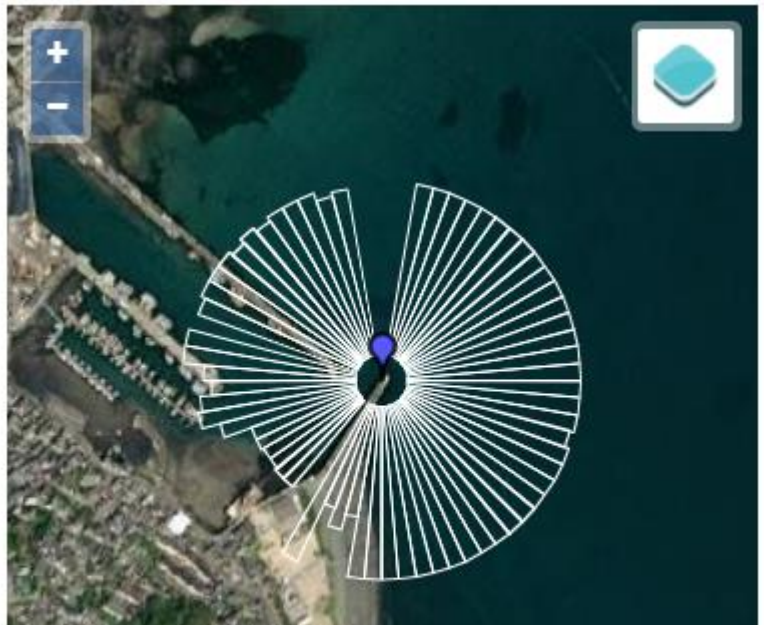
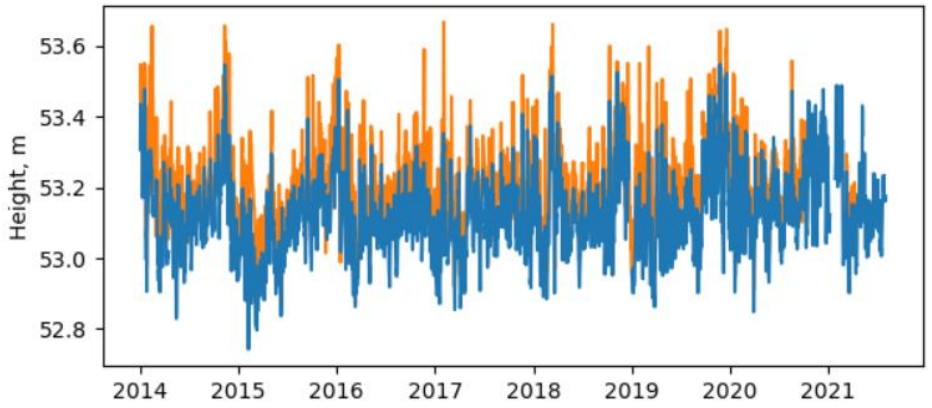
THE PSMSL GNSS-IR DATA PORTAL

DATA PORTAL AT [HTTPS://PSMSL.ORG/DATA/GNSSIR](https://psmsl.org/data/gnssir)





Blue: GNSS-IR Data, Orange: Nearby tide gauge data

GNSS-IR Site Map

- Good site - reflectometry works well and data is available
- Decommissioned - reflectometry works well, data is available, but site is no longer operating
- Questionable - reflectometry works sometimes or the signal is very weak probably due to location
- Bad - no data available at the site, either due to positioning of the sensor, lack of signal to noise ratio data, or data sampling is inadequate for the height of the sensor

THINGS TO KNOW ABOUT THE DATA

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Example notebook: https://psmsl.org/data/gnssir/gnssir_example.html

Simple csv format – one liner to read in Python (Pandas), Matlab, perhaps R?

time	raw_height	adjusted_height	fitted_tide	prn	signal	azimuth	elevation
2014-01-01 00:24:30	51.435	52.065	51.953	107	1	250.881	12.907
2014-01-01 00:34:45	51.373	52.363	52.159	219	1	258.202	12.845
2014-01-01 00:34:45	51.415	52.405	52.159	219	5	258.202	12.845
2014-01-01 00:34:45	51.218	52.208	52.159	219	7	258.202	12.845
2014-01-01 02:44:29	54.251	54.878	54.795	2	2	37.505	12.921

Time steps are irregular – observations represent one passing of a GNSS satellite overhead

THINGS TO KNOW ABOUT THE DATA

National Oceanography Centre

Example notebook: https://psmsl.org/data/gnssir/gnssir_example.html

Simple csv format – one liner to read in Python (Pandas), Matlab, perhaps R?

Which Satellite?
1-99: GPS
101-199: GLONASS
201-299: Galileo
301-400: BeiDou

time	raw_height	adjusted_height	fitted_tide	prn	signal	azimuth	elevation
2014-01-01 00:24:30	51.435	52.065	51.953	107	1	250.881	12.907
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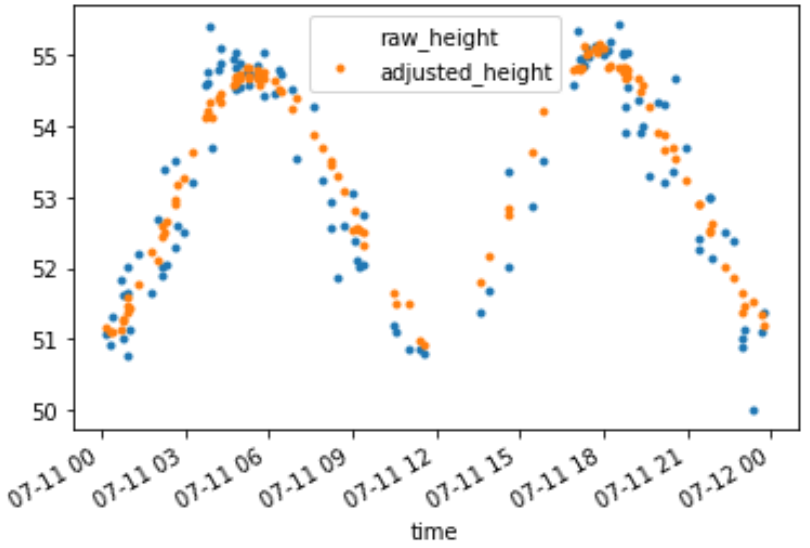
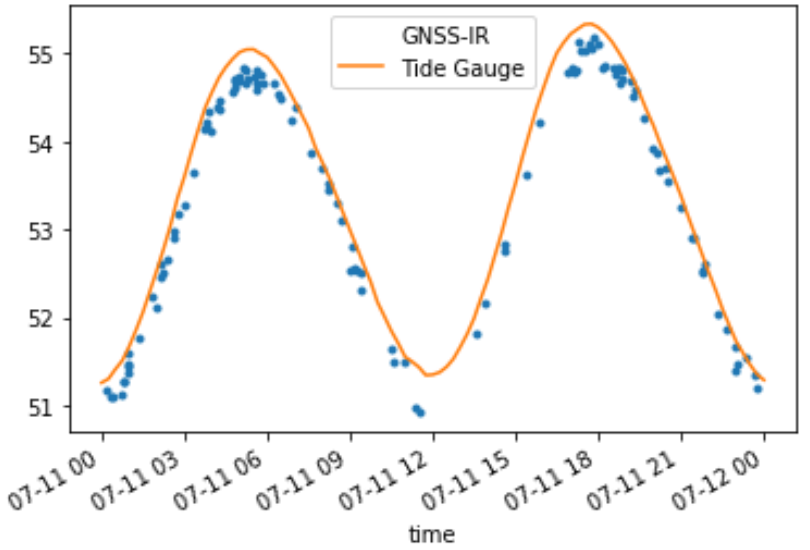
Time steps are not unique
Satellites transmit multiple frequencies, which are processed separately
Different channels may have different biases

Which channel?

MORE THINGS TO KNOW ABOUT THE DATA

- We provide two heights: **“raw”** and **“adjusted”**
  adjusted accounts for the vertical movement of the sea as the satellite passes overhead.
- GNSS measurements are geocentric, but!
  These data are **relative sea levels**
- We’ve used **approximate ellipsoidal height** as a datum, but if you’re comparing with geocentric data (e.g. satellite altimetry), you’ll need to account for land movement (using direct GNSS observations).
- This is delayed mode processing (although we have proof of concept it can be done in near real time)





OTHER USEFUL GNSS-IR PAGES

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https://psmsl.org/data/gnssir/useful_files.php

Other useful files

This page describes various data files used in producing our website that might be useful to you while using our GNSS-IR data. Where files are marked with an "e.g." and reference ID 10001, there is one file available for each site, and you can replace it with the ID of the site you are interested in.

id_mapping.csv

This is a simple, comma separated file, mapping our site IDs to the IGS-type IDs commonly used elsewhere. Note we've avoided using these as our identifier as they aren't always globally unique.

sites.json

This is a JSON file containing the information used in producing the table of sites, and a few extra fields such as data supplier. The file is structured as a dictionary, with each entry mapping one of our IDs to the metadata for that site.

good_sites.json

The data file used to create the layer of pins on our map page showing sites where GNSS-IR works well. This file is in the GeoJSON format commonly used by web mapping software.

Three other files describe the other layers on that map: questionable_sites.json, bad_sites.json, and decommissioned_sites.json.

10001.zip (e.g.)

The main data file for each site, as described on our data format page

10001.json (e.g.)

This is the data used to populate the site page for each location. It is in GeoJSON format to allow it to be added to the map on the page - most of the metadata fields are in the "properties" property of the object.

10001_daily.csv (e.g.)

CSV files containing daily averages (see our example notebook for how these are calculated) from the processed GNSS-IR data, along with daily averages from nearby tide gauges where available. These files are used in the daily plots on our station pages.

https://psmsl.org/data/gnssir/gnssir_example.html
https://psmsl.org/data/gnssir/gnssir_daily_means.html

Using GNSS-IR data in Python

This document shows the contents of the GNSS-IR data files distributed by the PSMSL, and how to use them in Python. Here we are using the Pandas data analysis toolbox, and we'll also need to have the matplotlib library available to create the plots.

```
In [1]: import pandas as pd
```

Loading data

We're going to be using data from Newlyn in south-west England here. First, we read in the data file. This is a zip files contains a csv file, and pandas will read the csv file within the zip seamlessly.

We're ignoring the header lines beginning with a # (although these contain valuable metadata, so do consider them later), and telling python to use the time column as an index for the data returned, and parse the date strings into python datetime objects.

```
In [2]: data = pd.read_csv('https://psmsl.org/data/gnssir/data/main/10049.zip', comment='#', index_col='time', parse_dates=True)
```

Let's take a look at what the data looks like by showing the first few rows.

```
In [3]: data.head()
```

Out[3]:

time	raw_height	adjusted_height	fitted_tide	prn	signal	azimuth	elevation
2014-01-01 00:24:30	51.435	52.065	51.953	107	1	250.881	12.907
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FUTURE PLANS

National Oceanography Centre

- We are developing a mechanism to deliver NRT GNSS-IR data through ERDDAP
- In the future we hope to improve the metadata available for each GNSS receiver to provide proper credit to the agencies involved in collecting the data, and making identifying where data comes from easier.
- Operators of GNSS sites near bodies of water can assist us by ensuring the signal-to-noise ratio is recorded in RINEX files (using RINEX version 3 or 4) and recording all constellations and frequencies possible. Please tell us about your site by emailing psmsl@noc.ac.uk - photographs and maps are very useful for establishing areas around the receiver likely to produce genuine reflections off the water

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THANK YOU

PSMSL GNSS-IR Portal: https://psmsl.org/data/gnssir/

Kristine Larson’s Web App: https://gnss-reflections.org/

Kristine’s YouTube channel: https://www.youtube.com/@funwithgps