Geophysics on a Budget

opensource research level science projects for schools

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www.schoolphysicsprojects.org

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Rationale I

I firmly believe that it is possible for a school, particularly an 11-18 school or sixth form to build an ongoing science enrichment program which permits students to engage in real research. This would open up the possibility of ongoing engagement with researchers and contributing to real papers. Indeed a few bold schools in the UK Simon Langton Grammar School have done this. Regrettably rare in the UK this type of collabaration is much more common on the continent with programs such as HiSparc.

Rather than provide a pre-built, polished design our intent was to provide proven initial designs that can be quickly built and got running in a school. This could easily lead to students testing and making improvements or simply gathering and analysing data. The software is written in python to allow easy adaptation by students.

Educational Benefits I

Few pre-university science students have direct experience of real science. Projects such as this can combine real science with real-world systems engineering. Students may work in teams to build, test and install rather sophisticated real-time geophysics monitoring systems. When the initial install is up and running it can them be further developed, different pressure sensors, various wind-shields such as porous hose may be tested, wireless links between the sensor and base station, statistical filters added to the software. The systems are designed this to be sufficiently simple to allow construction by 11-16 yr olds (this has been done) whilst offering sufficient development potential for older students. Students are attracted to the combination of physics, computing and electronics along with space science and geophysics.

Educational Benefits II

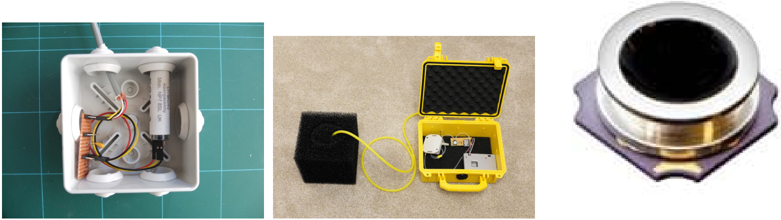
Geophysics is under-appreciated, even at A-level despite the stellar career prospects. Projects such as this could stimulate interest in geology, physics and computing. The hardware costs are small, each sensor rig will cost no more than £100, less if one has a spare P.C. or Raspberry Pi.

In the case of our infrasound sensor there are few national infrasound networks outside those operated under the aegis of the C.T.B.T.O. The only one in the U.K. is operated by A.W.E. who are *rather* secretive.
Seismometer networks such as IRIS have proved very popular with schools. Infrasound is a new field and national networks of infra-sound stations could generate much interest in budding physicists and geologists as well as producing real scientific data.

To Date

1. HiSparc Muon Detector
2. Building networked seismometers
3. Lightning Detector.
4. 'Programming for Scientists' courses.
5. Introduction to LaTeX.
6. Design a Chip - digital design in VHDL
7. Aurora Monitoring Station.
8. Infrasound Station.
9. Microbarometer Station.

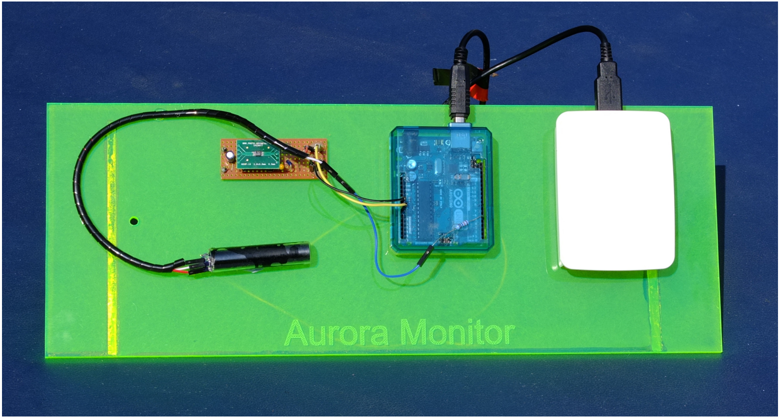
Current Projects



Aurora Monitor —— Infrasound ——Microbarometer

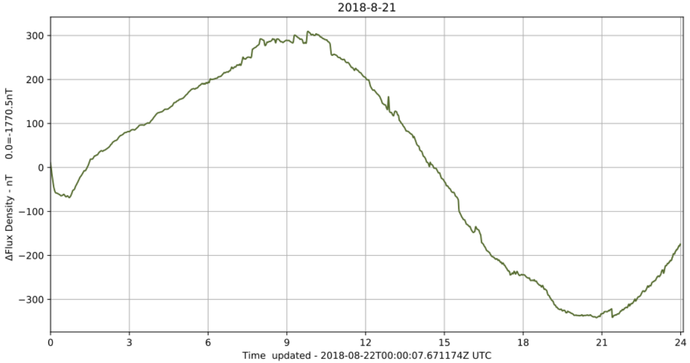
All 3 projects consist of a low-cost though sensitive sensor with data being processed, plotted and stored by a Raspberry Pi. The R.PI then uploads plots to a school website. If anything looks interesting the data can be retrieved over the network for further analysis.

Aurora Monitor



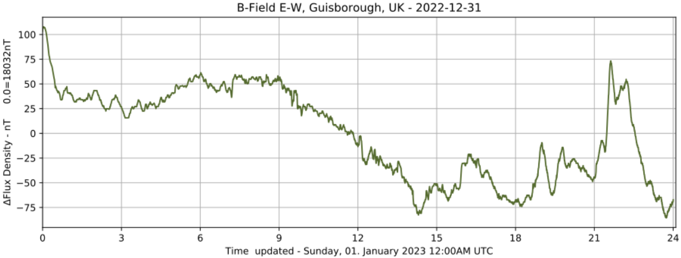
Aurora Monitor

Aurora Monitor



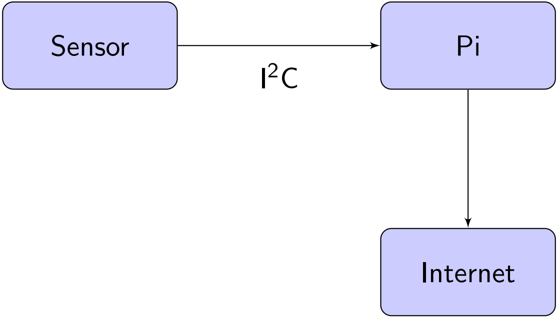
Aurora Monitor - quiescence

Aurora Monitor



Aurora Monitor - strong solar activity

System Overview

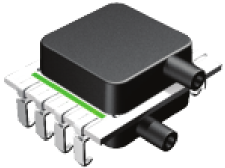


System Overview

Infrasound Monitor

CTBTO infrasound 'pipe array' in Greenland.

Infrasound m.e.m.s. Sensor

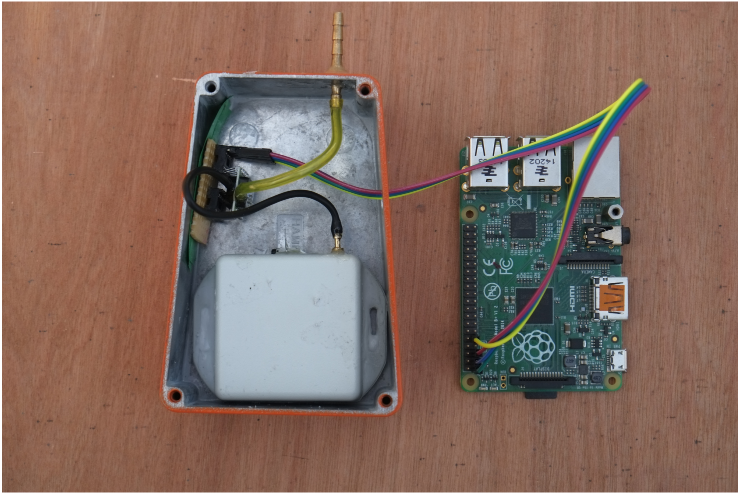


The system's sensor is the Amphenol DLVR-F50D, a micro-electromechanical system (mems) where both electronic and mechanical components are fabricated on silicon. This particular device is a piezo-resistive differential pressure sensor with inbuilt temperature compensation. It internally converts the varying analog voltage across a silicon membrane into a digital signal which is transmitted over a 2 wire output using the I^2C protocol. The sensor's range of $\pm$ 125Pa is divided into 6,553 steps giving a resolution of $<$ 0.04 Pa. It is very simple to use with only 4 connections required. Gnd and +3.3V inputs are taken directly from the Raspberry Pi's header pins whilst the two I^2C outputs (SDA & SCL) lead back to the Pi.

Raspberry Pi

The Raspberry Pi is the workhorse of the system. Software has been written in Python which interrogates the mems sensor approximately 140 times per second. These pressure readings are stored every hour until midnight when the cumulative day's readings are saved and a new day's recording begun. Hourly two plots , one of raw pressure and one of acoustic power are generated and saved to disc. These are uploaded to a remote website hourly via ftp by a crontab script. The entire system draws about 8 watts and has been left running unattended now for over 2 years. Data are viewed and downloaded for detailed analysis over the Internet.

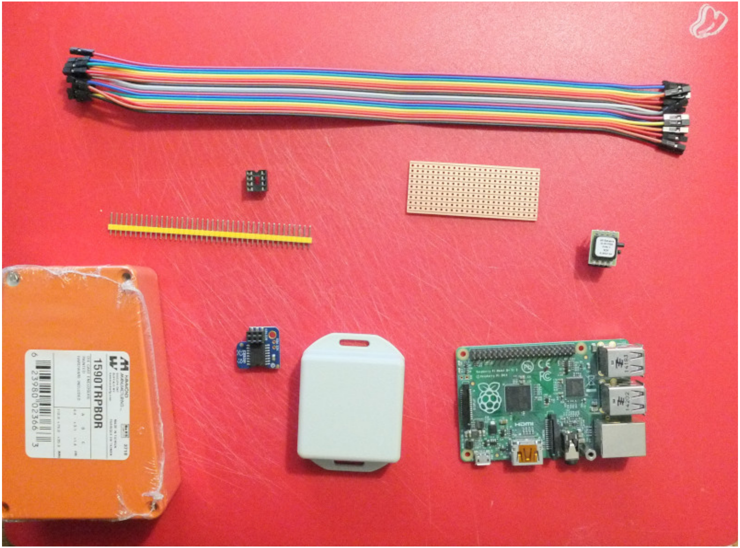
Raspberry Pi



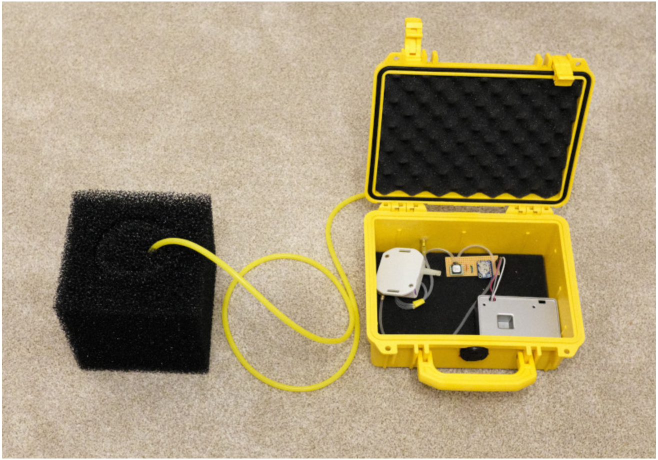
Complete rig no 3 - Gamma

Greenland Rig

Greenland Rig



Greenland Rig



Ruggedised Greenland Rig

Windfilter

Air turbulance across the sensor input leads to noise, this becoming more pronounced at lower frequencies. Some sort of wind-filter is thus desirable. Many different designs have been investigated - indeed this area appears ripe for original studies by students. Filters can be thought of as averaging local pressure variations across their surface, i.e. random turbulence causing a higher pressure at one part of the filter is likely to be negated by a similarly lower pressure elsewhere whilst the desired low frequency coherent signal is passed.

Pond Filter Wind Suppressor

Common filers include; pipes, porous hose, buckets of gravel, foam blocks and tents. Notably missing from literature is the humble loft-space.

Windfilter II

A simple loftspace appears to do a good job of reducing noise presumably as localised pressure variations cancel across its large surface. We have had two rigs running since 2018. One in a domestic loft whilst the other is 8m away, outside in the lee of an 8ft fence with a 30cl square foam pond filter acting as both noise and environmental filter. Despite the external rig requiring a 2m hose, of 2mm bore, running from the foam wind-shield it typically records absolute pressure variations almost double those of the loft-space.

For over 3 years we have tested the use of porous 'garden sprinkler' hose. A 20m length was adapted by plugging both ends. From one plug emerges a narrow flexible tube to the sensor head. This can be laid on the ground in a spiral or straight line. Tests on an exposed windy beach and a flat suburban roof indicate that the hose performed better than the foam block at noise reduction.

Windfilter III

Pond filter tested alongside porous hose

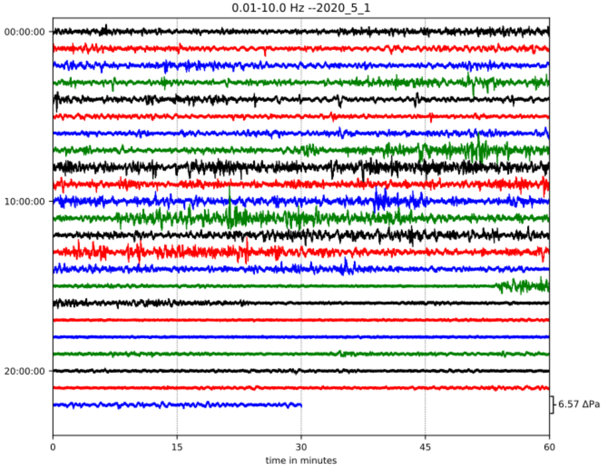
Data Analysis

The static device may left in some dusty forgotten corner of a loft-space or outbuilding uploading plots to a website. When some notable event occurs, such as a storm or sonic boom one downloads the raw data file for more detailed analysis

ObsPy
A Python Framework for Seismology

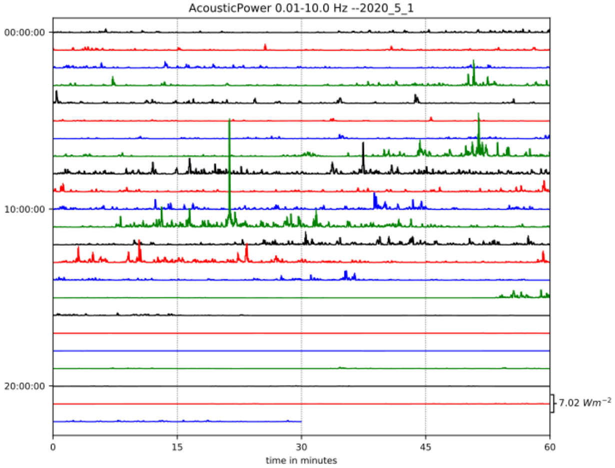
Data are saved in the geophysics standard *.mseed* format permitting signal analysis using a range of geophysics software. Routines have been written in the open-source Python ObsPy suite to facilitate a range of analysis. These may be readily extended by keen students giving a valuable insight into programming and such signal processing techniques as Fourier Analysis. A general purpose Python program has been developed to give students a start on this.

Data Analysis - Daily Plots I



Raw pressure plot auto generated and uploaded to web by Pi.

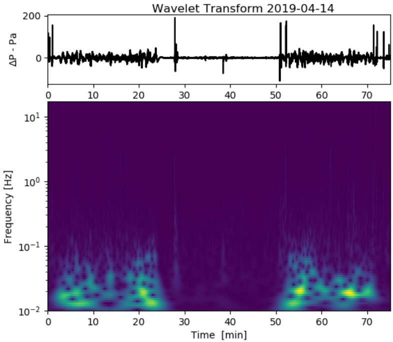
Data Analysis - Daily Plots II



Acoustic power plot auto generated and uploaded to web by Pi.

Wind Turbine

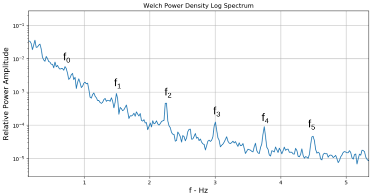
On a blustery day we took readings some 100m from a local wind-turbine using a spiralled 20m porous hose as a wind-filter. Interestingly infrasound levels during the car journey dwarfed those at the site itself .



Quiet gap in centre is windfarm, either side .. car journey

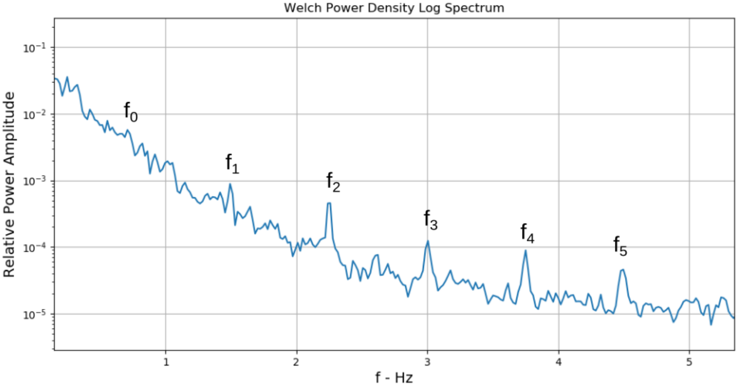
Wind Turbine II

Using the Obspy python routines a student analysed the signals. Having filmed the turbine he determined a 'blade pass frequency' of 0.75Hz. He could reasonably expect this to be the fundamental frequency f_0 and see signals at this and its harmonics nf_0. After trying various F.F.T. visualisations he did, exactly where predicted except for f_0 which, whilst strong, was masked by noise (note: log-log scale)



Wind Turbine: f.f.t. showing fundamental and harmonics

Wind Turbine III

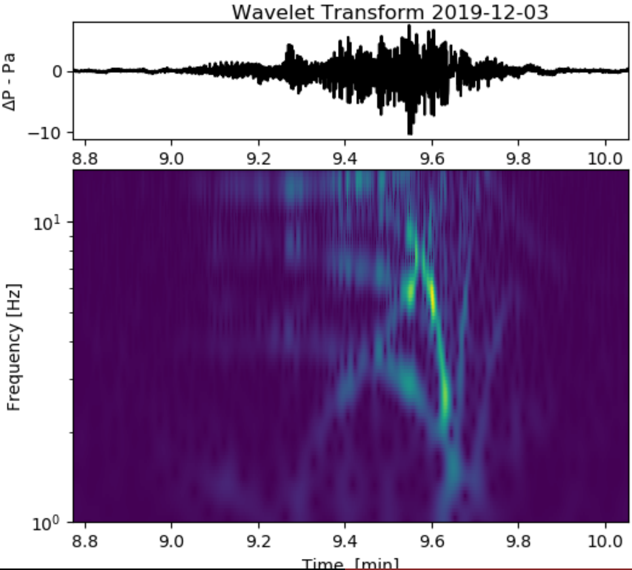


Wind Turbine: f.f.t. showing fundamental and harmonics

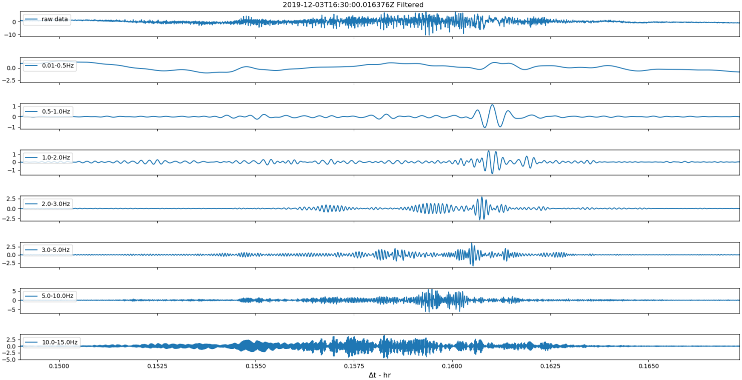
Helicopter

A Chinook helicopter passed overhead with clear signals picked up by both monitors (loftspace and outside). A simple wavelet analysis shows a clear signal in the 5-12Hz range, with clean sin components at 2-3Hz - following slides.

Helicopter - wavelet transform



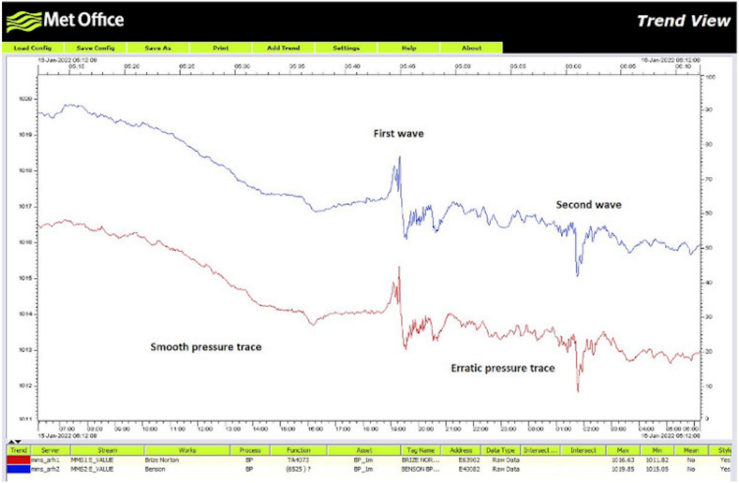
Helicopter - acoustic power bands



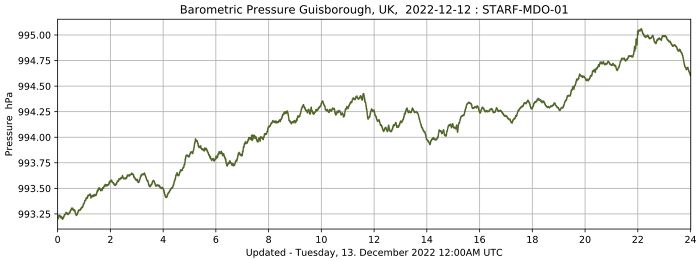
Cheap Microbarometer

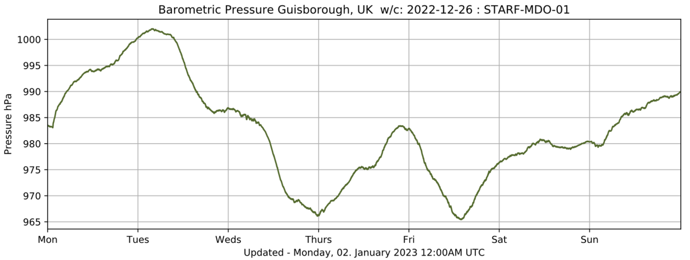
This project complements our infrasound monitor. A microbarometer with approx 1Pa resolution and 0.4Pa noise threshold based on the digital ICP-10125 i2c enabled absolute pressure sensor. The sensor is interfaced with a Raspberry Pi providing signal processing, saving data in .mseed format, plotting and then uploading plots here. System has performance of research/professional systems at a fraction of the price. A full rig, premounted sensor and a Raspberry Pi costing approx £70.

Tonga Eruption

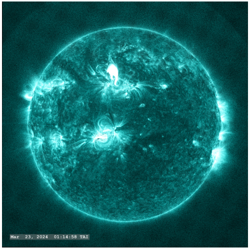


Microbarometer plots



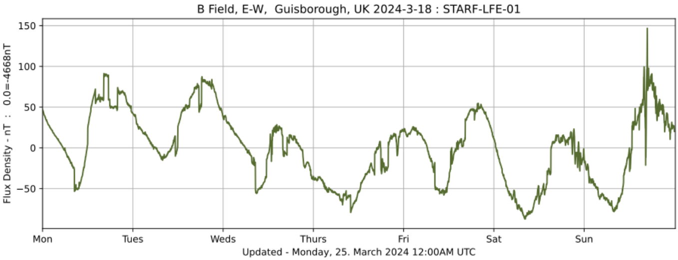


Observation of a magnitude X1.1 Solar Flare and associated C.M.E.

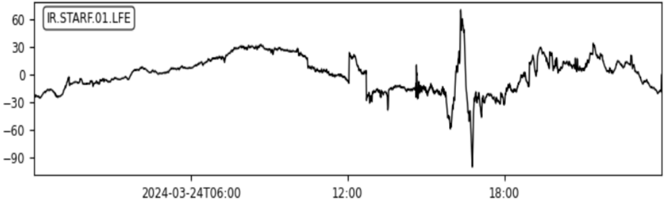


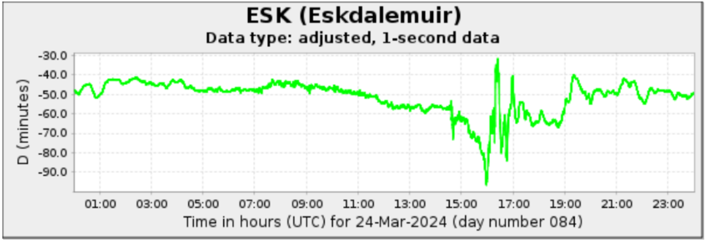
Early on Saturday 23 March 2024, the Sun released a strong X1.1 solar flare, the most powerful possible type, from a particularly active region pointing directly towards Earth. The earth field magnetometer detected a sharp variation in the earths magnetic field corresponding to the arrival of a bubble of solar material ejected by this C.M.E. 40 hours later. A similar signal was recorded by B.G.S. magnetometers in Scotland. Comparison of this system's plots with those from professional geophysics magnetometry stations help validate this system as capable of generating research grade data at low cost

Week plot


B Field, E-W, Guisborough, UK 2024-3-18 : STARF-LFE-01
Flux Density - nT : 0.0=-4668nT
150
100
50
0
−50
Mon
Tues
Weds
Thurs
Fri
Sat
Sun
Updated - Monday, 25. March 2024 12:00AM UTC

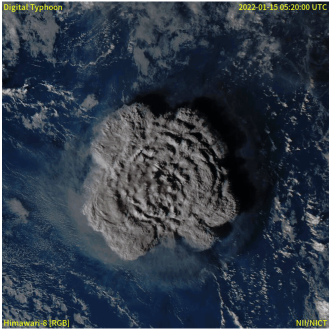
Day plot vs B.G.S. Magnetometer - Eskdalemuir



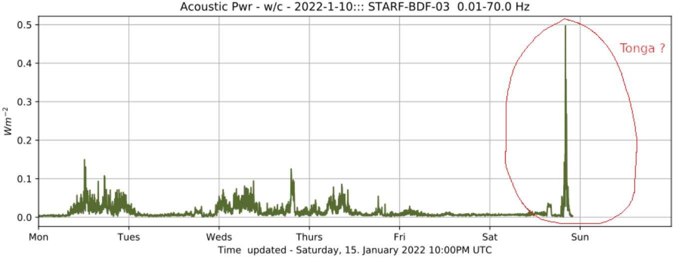


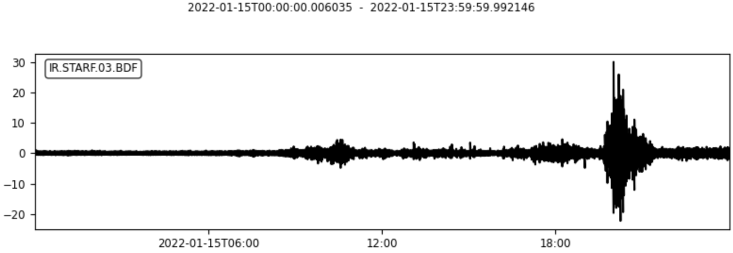
Tonga Eruption

On 15-January 2022 the Hunga Tonga–Hunga Ha-apai submarine volcano in the southern Pacific Ocean erupted in the likely largest atmospheric explosion since Krakatoa. We were able to pick up a clear primary pulse, remarkable given the 13hr travel time from 1650 km away.

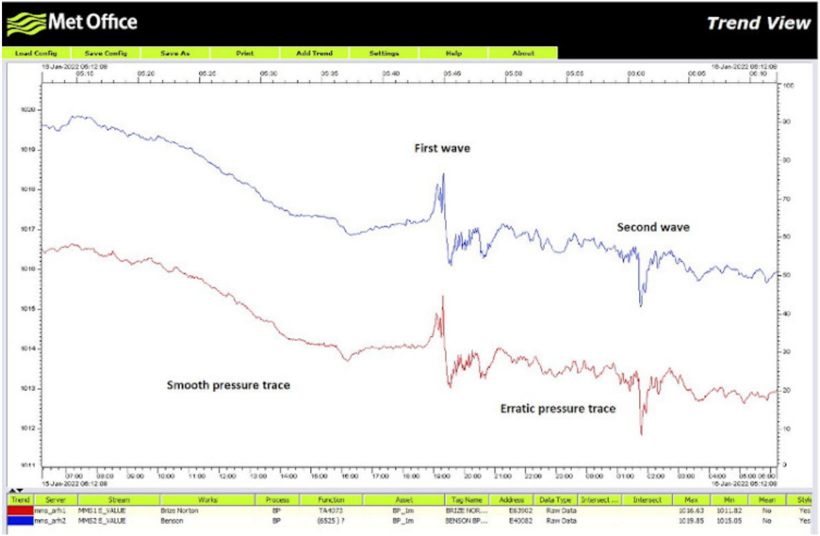


Success - Tonga Eruption





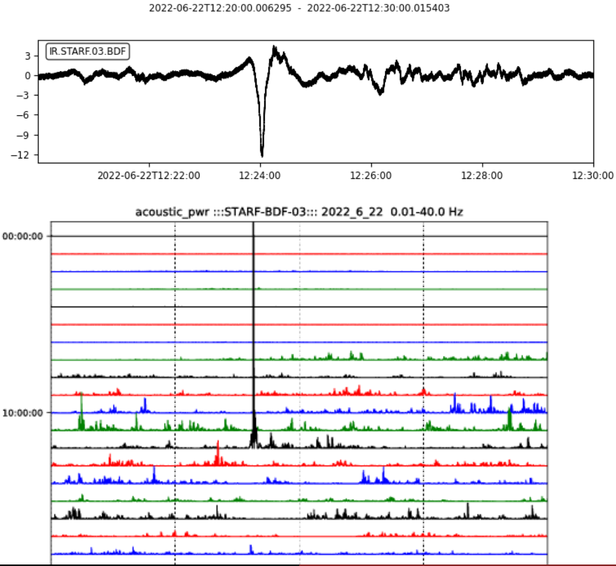
Success - Tonga Eruption II



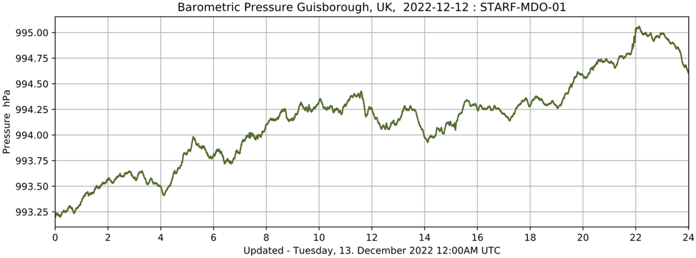
Atmospheric Explosions

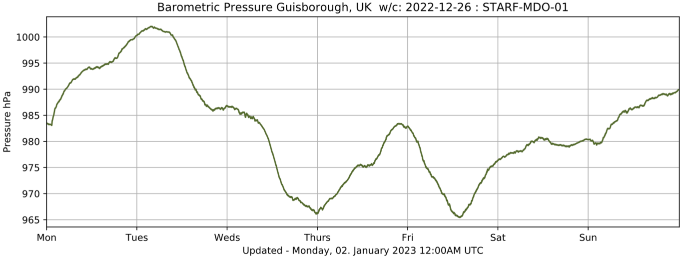
Slide Redacted

Microbarometer



Microbarometer plots





The Code

Stable well-tested python code suitable for long-term recording of such as seismic data. This be easily adapted to record a range of input signals periodically producing plots for uploading to the web. Data are saved in timestamped .mseed format for ease of analysis by standard seismic software.

```
# -----------------------------------------------
calc average of last minute's values storing in weekly_readings
if UTCDateTime().minute != minute_start.minute:
    if n_prev_minute > 0:
        mean_pressure = calc_acoustic_pwr(
            tranche_prev_minute[0:n_prev_minute, 0], n_prev_minute)
        mean_temperature = np.average(
            tranche_prev_minute[0:n_prev_minute, 1])
        weekly_readings[n_weekly_readings, 0] = mean_pressure
        weekly_readings[n_weekly_readings, 1] = mean_temperature

        q_prev_168hrs_data[hp_prev_168hrs_data, 0] = mean_pressure
        q_prev_168hrs_data[hp_prev_168hrs_data, 1] = mean_temperature

        # add 1 to hp wrapping around to 0 if > N_TARGET_WEEKLY_SAMPLES % = 'mod'
        hp_prev_168hrs_data = (hp_prev_168hrs_data +
                               1) % N_TARGET_WEEKLY_SAMPLES
        # reset tranche to all zeros
        tranche_prev_minute = np.zeros(
            [N_TARGET_PREV_MINUTE, 2], dtype=np.float32)
        n_weekly_readings = n_weekly_readings + 1
        minute_start = UTCDateTime()
        n_prev_minute = 0
```

Analysis routines have also been written.

2024 - Networking

We will be introducing networking of sensor rigs. Stations will be able to automaticaly upload their data to a central server. The server will then supply data and plots on demand, this is common the publically availible geoscience data.

This will permit the writing of fairly simple routine to identify *coincidences* - data events correlating between different stations.

Conincidences from 3 infrasound stations can be analysed to identify a source's location.

This is all well within the capabilities of A-level maths & physics students.

Linking to national networks

Once we have networking of stations on a firm footing we intend approaching national bodies - such as the British Geological Survey, B.G.S. for their imprimatur and possibly funding.
For the next year or two we intend funding a central server ourselves.

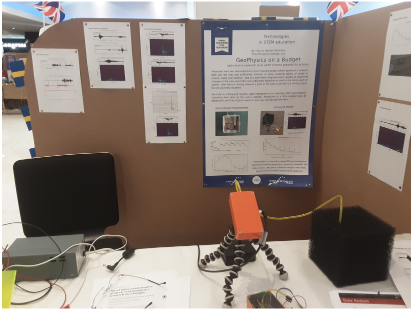
Summary

In our experience it is quite possible for pre-university 11-18 students to build research-grade geophysics sensing systems using modern low-cost digital sensors coupled to PCs or RPIs.
In my direct experience there is considerable merit in giving students the opportunity to develop their science interests in extra-curricula science 'clubs'. I have lost track of the number who explained how their university interview was dominated by discussion of such extra-curricula work.
Whilst regrettably rare in the UK such advanced science project work is common in much of Europe and the US. Here it is not uncommon for pre-university students to engage in original research. There is no reason why an ordinary UK school cannot make a big impact for little resourcing.

Displays

These systems - and the code - have attracted interest from Europe, US and Canada.

We have displayed at a number of MakerFaires and at SONS-2022 in Prague.



Suggested timings

Group of 4-6 interested students

- Term 1 at 1 hour per week - build rig and test interfacing with a Pi
- Term 2 Network at your establishment - create a web page to display plots.
- Term 3 Get into data analysis

Following years

- Calibrate sensors
- Rework monitoring software
- Take readings at points of interest i.e. Infrasound at seafront, in cars, near wind turbines.
- Write a paper on the above.

Summary

I am committed to setting up national/international class STEM programs in the sort of geophysics/space-science projects described here. These are well suited to school or college science clubs/enrichment activities either on one site or as part of a distributed network between schools. The projects here are cheap, research-level and released open-source. Feel free to have a go at them.

Interested?

Feel free to contact me. Detailed construction instructions and software can be downloaded from

`www.schoolphysicsprojects.org`

Two peer-reviewed papers have been published in IOP Journal of Physics Education

Authors

Ian has taught physics, computing, electronics & engineering in 6^{th} Forms for over 30 years - periodically running electronics/coding projects in primary & secondary schools. I recently completed a Ph.D in Computational Physics involving the Monte Carlo simulation of lattice gases. Outside of the day job I am developing a number of educational projects in geophysics, computational physics and digital electronics.

Saul and Nathan are now reading mathematics and physics at Durham University.

With great thanks to all the students over the years who have persevered in the teeth of my somewhat chaotic approach to project work.

The authors have no commercial interest in these projects nor with any equipment supplier. They have been entirely self-funded, pro-bono with designs and code released open-source.