

## Deployment of Portable Infrasond Sites to Assess Feasibility of Additional Elements, I51GB, Bermuda, UK

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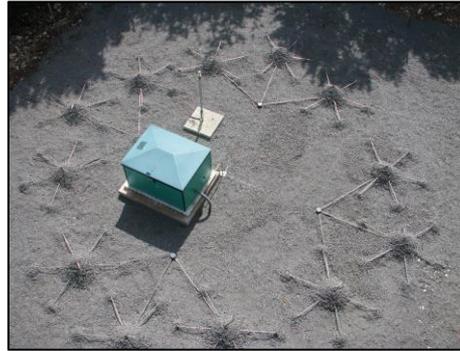
IMS infrasonde station I51GB, located on the island of Bermuda in the Atlantic Ocean, was certified in December 2008. The original installation presented many design challenges driven by land availability, island topography and proximity to populous zones. These challenges not only dictated the amount of element sites that could be installed, but also the geometry of the station. The array geometry of I51GB is atypical for an International Monitoring System (IMS) infrasonde station, comprising of a large aperture, rectangular, four-element array. Adding to the uniqueness of the site locations, is the large lagoon that lies directly between all elements. In late 2018, after several incidents of vandalism rendered some elements inoperable, the Provisional Technical Secretariat (PTS) was approached regarding the feasibility of relocating existing sites to more secure locations, which had become available since the original station installation. In September 2019, with cooperation of the Station Operator (SO), the Bermuda Airport Authority, the PTS installed two portable infrasonde stations in parallel to the existing I51GB station. Data was collected on and off for roughly 10 months to allow for IMS station site survey requirements and to assess whether the additional elements would benefit station infrasonde event detection capabilities. Results from the site survey are summarized in this e-Poster.



INTRODUCTION



**Figure 2: 2008- Installation**



**Figure 3: 2008 - Certification**



**Figure 4: 2018 - Equipment Vandalism**



**Figure 1: 2000- Initial Site Survey**



The history of IMS infrasond station I51GB spans over 20 years, with the initial site survey taking place in September 2000. Due to difficulties in securing land for the station installation, I51GB was finally completed roughly 8 years later. In the years that followed, some elements experienced episodes of vandalism, occasionally rendering the station non-Mission Capable (<70% sites up). Even in the case of one site being inoperable, detection capabilities become less than optimal. In 2019 alone, there were stretches of multiple days without detections made at I51GB (Figure 6).



**Figure 5: 2019- Station Upgrades**

In late 2018, the SO approached the PTS about relocating elements to secure land with restricted public access. As the PTS was planning a 2019 upgrade visit to target both general maintenance and vandalism repairs, it was agreed that portable test equipment could be installed at the suggested locations for an extended period. An IMS site survey involves measuring pressure variations and weather conditions for a minimum of 15 continuous days at a specified location. In this case, it was agreed that the survey would be started after all four IMS sites were brought back online and sending data to Vienna. The goal would be to collect data that meets IMS site survey requirements, while at the same time combining the measurements with the I51GB data, creating a six-element array (Figure 7). The portable equipment (Figure 8) would be configured and installed by the PTS with maintenance and data collection to be performed by the SO. Though the deployment did experience some roadblocks, including a global pandemic and active hurricane seasons, the SO and the PTS were able to successfully complete the site survey by mid-September 2020.



Figure 7: I51GB plus H5 and H6

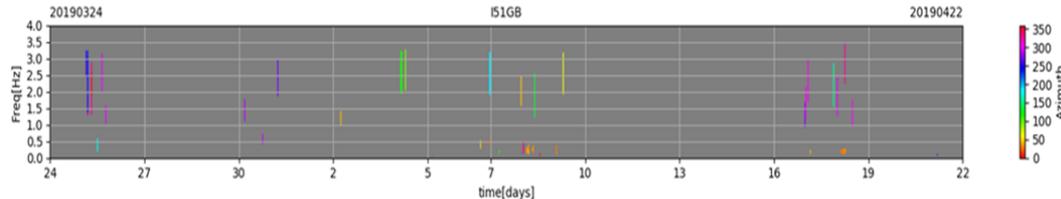


Figure 6: Time-frequency diagram of the detections at I51GB March-April 2019



Figure 8: Portable site equipment ready for deployment



Figure 9: Pre-deployment sensor testing, MB2005



Figure 10: H5 site deployment



Figure 11: H5 deployed at Doppler Site

METHODS

The first step of the survey was to ensure that all I51GB sites were operational and sending data to Vienna. Once this was achieved, the portable equipment was configured for installation. Preparation included digitizer configuration (matching that of an IMS network infrasound station, e.g. sample rate, compression, gain, etc.). In this case, both setups employed Nanometrics digitizers (I51GB/Europa-T, Portable/Centaur CTR4). In addition, all I51GB (MB2005, Martec, France) and portable site (MB3a, Seismowave, France) sensors were tested (Figure 9) to ensure that they met IMS requirements for both phase and amplitude response. A Gill GMX-500 digital meteorological station was also run at each portable site to record continuous wind speed and direction data. Deployment sites were agreed upon ahead of time and were situated on Bermuda Airport Authority land. These sites were targeted for security and access considerations. The sites were also chosen due to their infrastructure and future availability, in the case it would be decided to move forward with the permanent addition and/or relocation of the elements. The temporary deployment equipment was serviced by the SO (Figure 10), which included data retrieval and battery replacement. Recorded data (miniSEED) was forwarded to the PTS for review and archival. CD1.1 data from I51GB sites I51H1-I51H4 were also reviewed concurrently.

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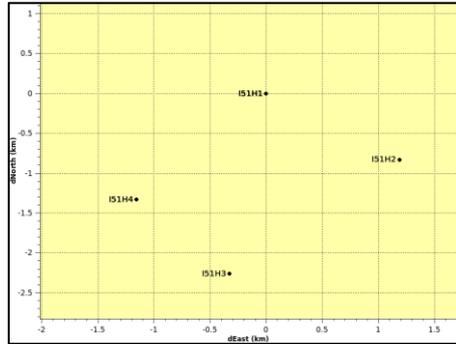


Figure 12: Current I51GB Array Geometry

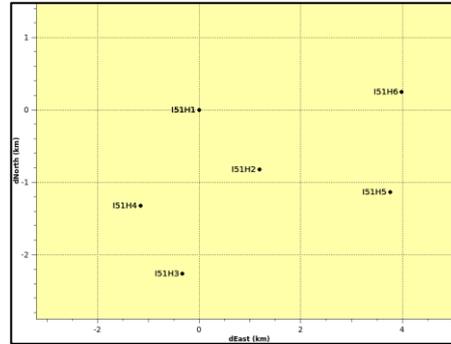


Figure 13: Proposed I51GB Array Geometry

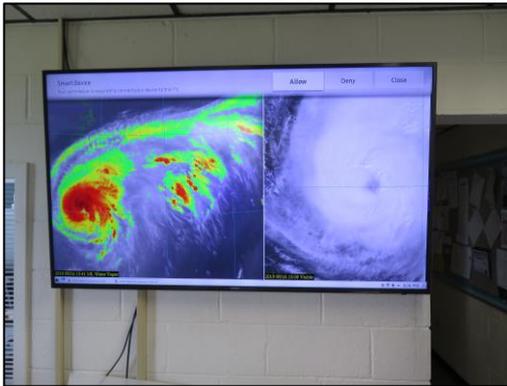


Figure 14: I51GB Data Check SEP 2019

MiniSEED data recovered by the SO, along with the CD1.1 data from I51GB were converted into CSS files with a single wfdisc table for each month. Data was then processed using DTK-(G)PMCC, which allowed for not only viewing the waveform data recorded at each site, but also plotting the meteorological data recorded at I51GB, along with both portable sites.

The goal in reviewing the recorded data was the following:

- 1) To ensure the survey met the IMS site survey requirements (i.e. 15 continuous days of data, determine acoustic noise levels at each site and to make MET measurements in parallel);
- 2) To determine if infrasound signals measured at H5 and H6 could participate in infrasound detections;
- 3) To determine if the inclusion of the H5 and H6 sites would improve upon the existing I51GB array geometry with regards to detection capabilities.



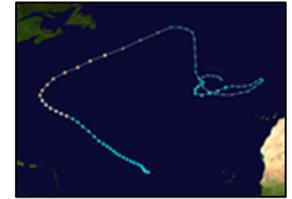
**Figure 15:** Hurricane Humberto approaching Bermuda, forcing storage of portable array, SEP 2019



**Figure 16:** Humberto: 13.09.19 -19.09.19



**Figure 17:** Jerry: 17.09.19 -24.09.19



**Figure 18:** Paulette: 07.09.20-22.09.20

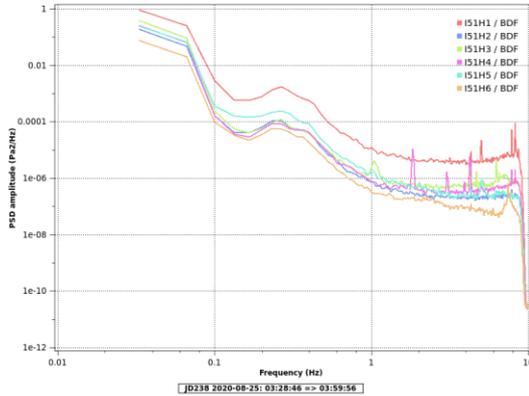
Successful collection of 15 days continuous data sets from both the H5 and H6 sites, along with all I51GB sites proved to be more challenging than initially anticipated. Immediately after the initial deployment of the portable equipment, the SO had to strike the equipment due to the imminent landfall of Hurricane Humberto (Figures 15 and 16). Shortly thereafter, *Jerry* paid a visit to Bermuda as a tropical storm (Figure 17). After these two events, it was decided to keep the portable equipment indoors until December/early January 2020 (outside of hurricane season).

A series of untimely outages in early 2020 hindered the collection of the required 15 days continuous data at all six sites. Unfortunately, once everything was back up and running, the COVID-19 pandemic was in full swing. Though restrictions hampered the ability to visit the portable equipment as often as desired, the SO was able to complete the needed tasks. Data was monitored throughout Q2-2020 and into the late September, when once again, a hurricane threatened Bermuda. With sufficient data collected and Hurricane Paulette approaching the island, it was agreed to end the deployment and to pack the equipment for the return trip to Vienna.

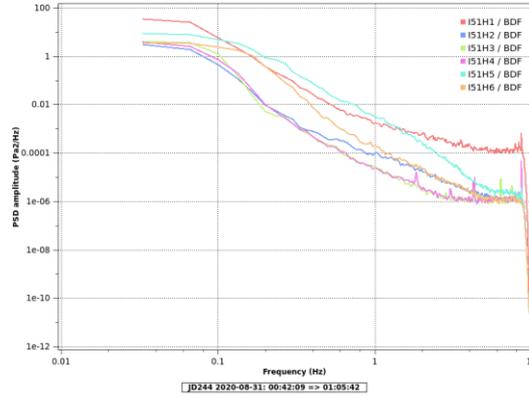


**Figure 19:** Data retrieval, H5

RESULTS continued

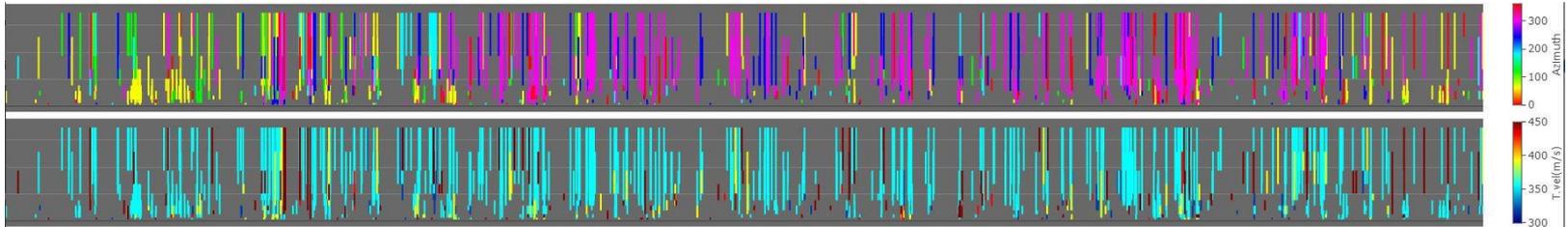


**Figure 20: Low wind day**



**Figure 21: Elevated wind day**

The completion of the I51GB upgrade, with all four elements back online, added greatly to the station's ability to make detections (see Figure 6 vs Figure 22). Except for I51H1 (possible scaling issue), review of power spectral density (PSD) calculations from the portable equipment vs. I51GB, showed similar performance in both low and elevated wind conditions (Figures 20 and 21). Wind-noise reduction systems (WNRS) are in place at I51GB, though in need of major repair. The portable equipment employed porous garden hoses as WNRS, though they become less effective over time (UV/weather damage). The spikes seen in Figures 20 and 21 are of unknown origin and were also noted during the 2000 site survey.

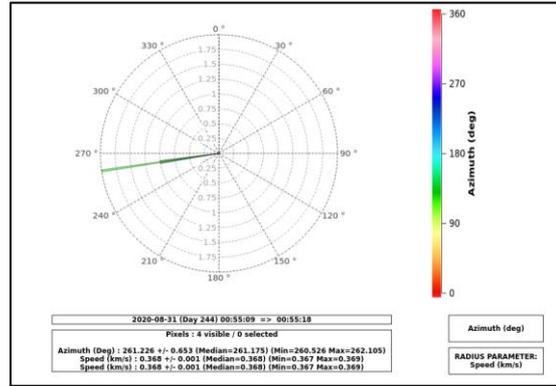


**Figure 22: Previous 365 Days**

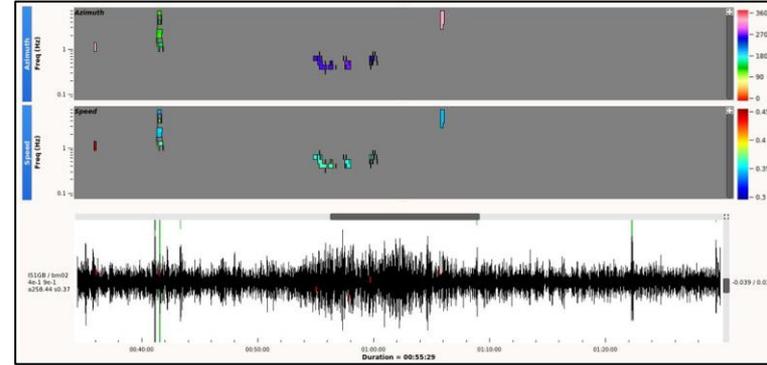
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**Figure 23:** 30-AUG-2020 event, SpaceX Rocket Launch, Florida, USA



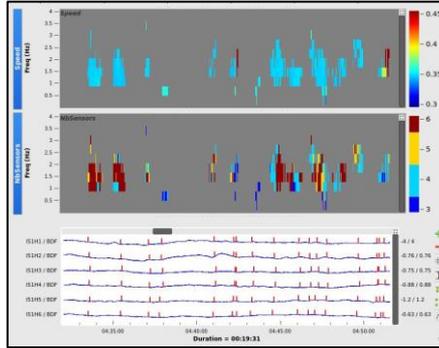
**Figure 24:** 30-AUG-2020 event detected by I51GB and portable equipment (arrival 31-AUG)



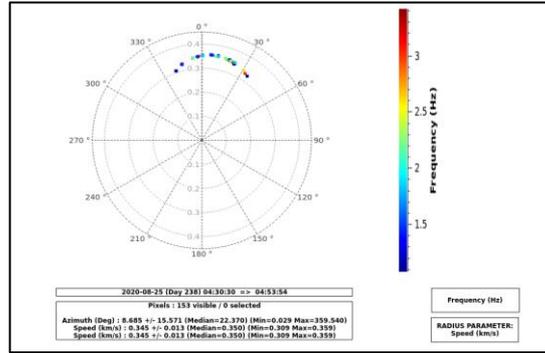
**Figure 25:** 30-AUG-2020 event PMCC detection, I51GB (arrival 31-AUG)

Reviewed Event Bulletin (REB)s provided by the International Data Centre in Vienna were checked to see if the station and portable equipment were able to detect events also measured by other infrasound stations in the IMS network. During 2020, very few REBs were associated with I51GB. The SpaceX rocket launch on 30-AUG-2020 (Florida, USA) was detected by I10CA, I18DK and I51GB (Figure 23). The infrasound signals attributed to this launch were recorded at I51GB (Figures 24 and 25) on 31-AUG, review of data sets from the station and the portable equipment did not provide evidence of improved detection capability, which could be attributed to the addition of H5 and H6 for this particular event. An REB event on 30-MAY-2020 was also reviewed, with the same outcome. In this case, only 3 sites at I51GB were functioning at the time of the rocket launch. The addition of H5 and H6 did not provide evidence of improved detection capability in this case either. In the case of the 30-AUG launch, noise levels were elevated (Figure 21) at all sites, notably below 1Hz at H5 and H6, which would degrade the detection capabilities of these sites.

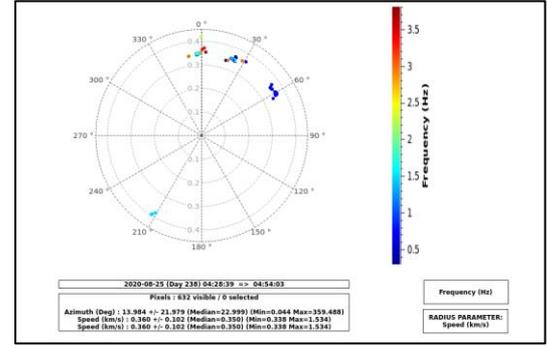
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**Figure 26:** 25-AUG-2020, I51GB including H5 and H6. Detections showing all six sensors participating



**Figure 27:** 25-AUG-2020 local detections I51H1, H5 and H6 only.



**Figure 28:** 25-AUG-2020 local detections, I51GB only

Local infrasonic events were detected often at all 6 sites (Figure 26), though typically made at higher frequencies (while still being within the IMS band of interest, i.e. below 4Hz). In the case of 25-AUG-2020, detections to the north of the island were made at all six sites, including both I51GB and the portable H5 and H6 sites. Removal of specific sites from the data processing showed that the test setup could still make detections in multiple configurations (Figures 27 and 28). This is important, as it indicates that the addition of H5 and H6 can assist in station detections in cases where other sites may be offline (e.g. power, sensor issue, etc.). It should be noted that though the addition of H5 and H6 would increase station detection capabilities, the addition of two sites would not improve I51GB's robustness to Mission Capability. This would require the addition of 3 elements, i.e. loss of two sites would result in >70% pressure channels being operational.

Note: The 25-AUG-2020 measurements shown here were made during periods of low local wind conditions.

RESULTS continued

CONCLUSIONS

The deployment sites were visited by PTS staff in 2000 and 2019 and assessed for both data quality and feasibility of permanent IMS equipment installation. The deployment of the portable equipment showed that the suggested sites substantially meet IMS requirements for installation and could add to the improvement of local infrasound source detections. It was not determined during this experiment whether the additional sites could improve detection of distant events, but it is assumed that the reduction of local wind-noise turbulence could assist. The report of WGB15 to the Preparatory Commission in 2001 recommended that IMS infrasound stations should be built with up to eight elements. Though the installation of 8 elements is not possible for multiple reasons, the addition of 1-2 elements is feasible. While the station currently will remain Mission Capable with the loss of one element (total of three), this loss (due to local noise or overall failure) will lower the station's ability to build detections. Though the installation of one or two elements will not increase the station's robustness to Mission Capability, the addition of elements will increase the station's ability to build detections. This follows the recommendation of the Expert Group in 2003 noting the benefit of adding additional elements in order to increase detection capabilities.

With new hardware and software tools available to PTS staff and Station Operators, similar deployments could be made at other IMS infrasound stations, while assessing site relocation or the addition of elements. Portable equipment "sites" are currently prepared at PTS facilities in Vienna and ready for deployment, not only station site surveys, but also measurement activities that may be of interest to other institutions and or/NDCs.



**Figure 29:** Ready for next deployment!

*Special thanks are given to Bermuda Airport Authority staff for their continued assistance with this experiment during most unusual circumstances!*

*In no specific order:*

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