Memo No. 117

The Portable Weather Station: 2022 Site Testing

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NRAO

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This document describes the site characterization activities at the Pohakuloa Training Area in 2022. It includes a description of the weather station design and early testing. We present details of the data collection, data analysis, and problems we encountered during deployment. We discuss the reasons for the final decision to exclude PTA as a candidate site location. A brief summary of lessons learned is included.

1 Background

The Mauna Kea (MK) VLBA station is crucial to both astronomical and geodetic operations of the VLBA. There is strong interest in having a Next Generation Very Large Array (ngVLA) station on the island of Hawai‘i. To this end, multiple candidate locations were identified by various groups. Each location needs to be characterized to ensure it will be a suitable location for a radio telescope. Certain weather conditions, especially water vapor content, have a significant impact on antennas operating at frequencies of ~ 12 GHz and higher.

One of the candidate locations was the Pohakuloa Training Area (PTA), operated by the US Army. Through discussions with the US Naval Observatory, it was decided that PTA would be the first site to be characterized for its weather conditions. The initial intention was to deploy a portable weather station on PTA property for a duration of 2 years.

2 NRAO Personnel

The following NRAO staff were involved in the construction and deployment of the portable weather station on PTA property:

- Justin Linford: Project Director
- Jon Cooper: Program Manager
- Patrick Martinez: Station design, construction, initial deployment and testing (NM)
- Tony Sylvester: Station deployment and maintenance (HI)
- Simeon Johnson: Station deployment and maintenance (HI)

NOTE: Tony Sylvester and Simeon Johnson received NRAO Star Awards for their work deploying, maintaining, and recovering the portable weather station.

3 The Portable Weather Station

NRAO personnel designed a Portable Weather Station (PWS) to be deployed on a vehicle trailer and parked at candidate site locations. The trailer chosen for the PWS was an Ironton model 37552 5ft x 8ft HD trailer. The trailer was modified to support more weight and to include 6 retractable support legs. The trailer tongue was also modified to properly attach to NRAO vehicles. A Larson Electronics thirty foot telescoping mast (LM-30-3S) was installed on the trailer, on which the various weather sensors were mounted. A standard truck bed tool box was attached for storing the sensors, cables, and tools during transit.

The PWS was designed to be robust enough to withstand various weather conditions, including high winds. A combination of trailer ballast (railroad rails) and wire supports ensured the trailer and mast could withstand wind speeds of up to $\sim$ 100 miles per hour. The base of each support leg included a hole for a ground stake. The PWS also included lightning protection with a lightning rod at the top of the mast and grounding wire that could be either buried or attached to a nearby metal fence. The trailer, support legs, and tool box were all painted using the same all-weather paint used on the VLA antennas. A security camera was included to both have a visual record of local weather conditions, and to monitor the local area for signs of intruders The PWS was designed to be powered by a solar panel and battery combination.

The PWS was designed to monitor air temperature, relative humidity, wind speed and direction, barometric pressure, solar irradiance, and rain fall. The dew point was calculated from the air temperature and relative humidity. The individual sensors mounted on the PWS are listed in Table 1. The PWS recorded data locally to the datalogger, and those data were collected remotely via a cellular module. All of the sensors, the datalogger, cables, and mounting hardware were obtained from Campbell Scientific. Remote interface with the datalogger was controlled by the Campbell Scientific LoggerNet software package. The datalogger, cellular module, and barometer were all stored in a weather-proof enclosure. The battery was stored in a separate weather-proof enclosure.

Table 1: PWS Components

Measurement	Sensor Name	Component Model	Number of Sensors
Air Temp. & Relative Humidity	CSL Digital Temperature & RH sensor	HygroVUE10-10-PW	3
Wind Speed & Direction	Wind Monitor-HD	05108-L37-PW	1
Barometric Pressure	Setra 278 Barometer	CS100-PT	1
Solar Irradiance	Apogee Digital Thermopile Pyranometer	CS320-33-PW	1
Rain Fall	HS Rain Gauge 0.01 inch Tip, 8-inch Orifice	TB4-L25-PW	1
Security Camera	CSC Outdoor Field Camera	CCFC-R2	1
...	Measurement and Control Datalogger	CR1000X-NA-ST-SW-CC	1
...	4G/3G Omni 2dBd Antenna	32262	1
...	4G LTE Cellular Module	CELL210-V-250-Y1	1

4 Initial Deployment and Testing

Beginning on 2022 April 05, the PWS was deployed on New Mexico Tech property in a fenced yard used by the Energetic Materials Research and Testing Center (EMRTC) for vehicle and parts storage. See Figure 1 for an image of the PWS as deployed at the EMRTC yard. The PWS datalogger began collecting data immediately after being turned on. Data were downloaded to a local NRAO machine using the LoggerNet software and the cellular communication module.

Initial testing revealed the rain fall sensor was not functioning properly. Inspection of the sensor revealed that some shipping material holding the tipping bucket in place had not been removed. Once the shipping material was removed, the rain sensor began functioning as expected. During the testing period, the PWS withstood winds gusts of up to 65 miles per hour.

The PWS was allowed to sit in the EMTRC yard until 2022 June 16, when it was disassembled and taken back to VLA site to prepare for shipment to Hawai'i. See Figure 2 for an image of the PWS as it was being towed out of the EMRTC yard.

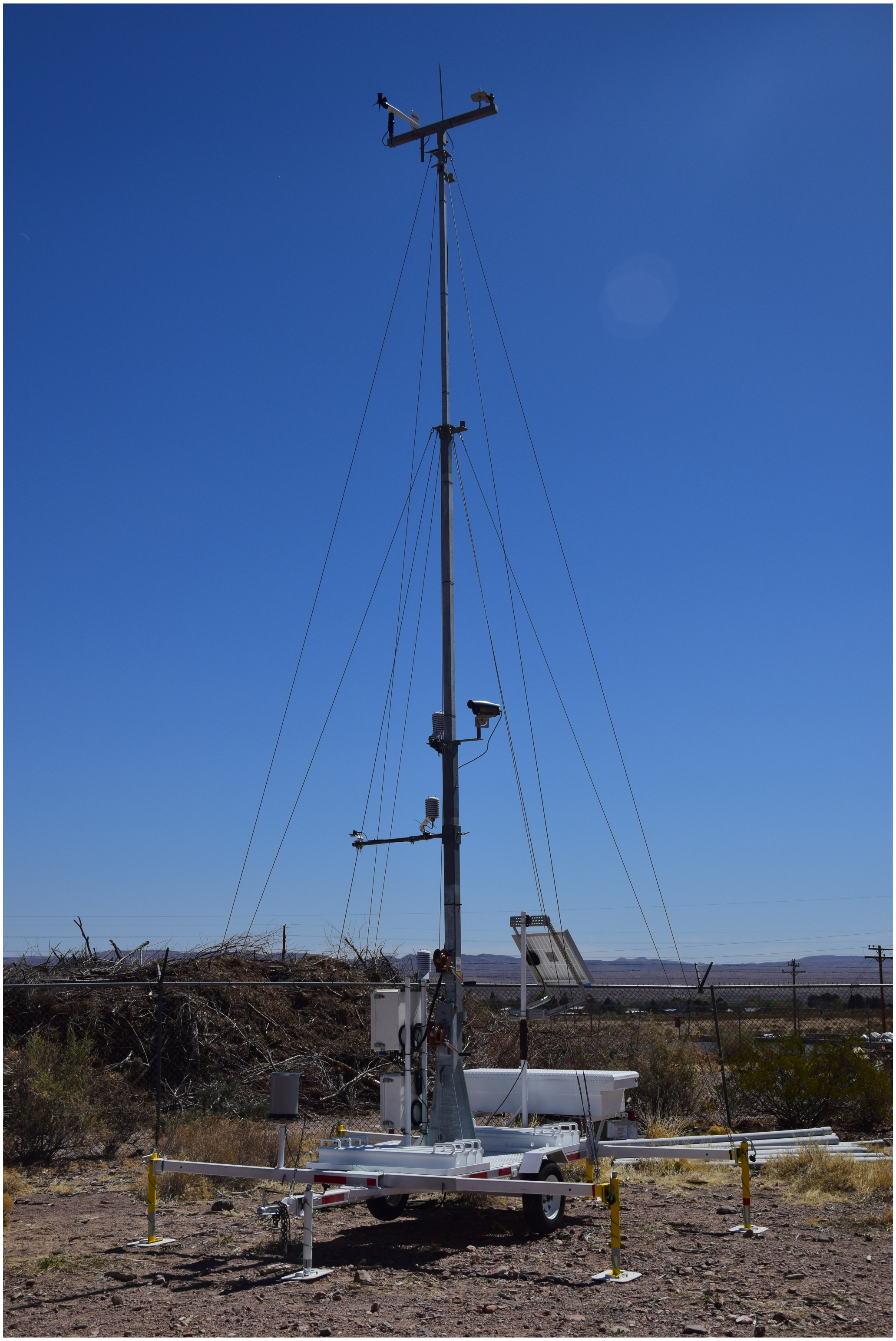

Figure 1: The Portable Weather Station, as deployed at the EMRTC yard, for testing purposes. Photo Credit: Justin Linford

Figure 2: The Portable Weather Station being towed away from the EMRTC yard. Photo Credit: Justin Linford

5 Data Collection

The PWS datalogger was set to record the following weather data:

- Minimum, maximum, and average temperature from each of the 3 temperature & relative humidity sensors
- Minimum, maximum, and average relative humidity from each of the 3 temperature & relative humidity sensors
- Minimum, maximum, and average wind speed from the wind monitor
- Average wind direction, and wind direction during the minimum and maximum speeds from the wind monitor
- Minimum, maximum, and average solar irradiance from the solar pyranometer
- Minimum, maximum, and average barometeric pressure from the barometer
- Rain fall from the rain gauge, based on the number of times the bucket tipped during the collection period

The PWS datalogger also calculated the minimum, maximum, and average dew point for each of the 3 temperature & relative humidity sensors, which also provide a vapor pressure measurement. The data collection cadence set the averaging time. The cadence for the testing period was 5 minutes.

In addition to the weather data, the datalogger also recorded various values to track overall system health. These values were recorded once per day.

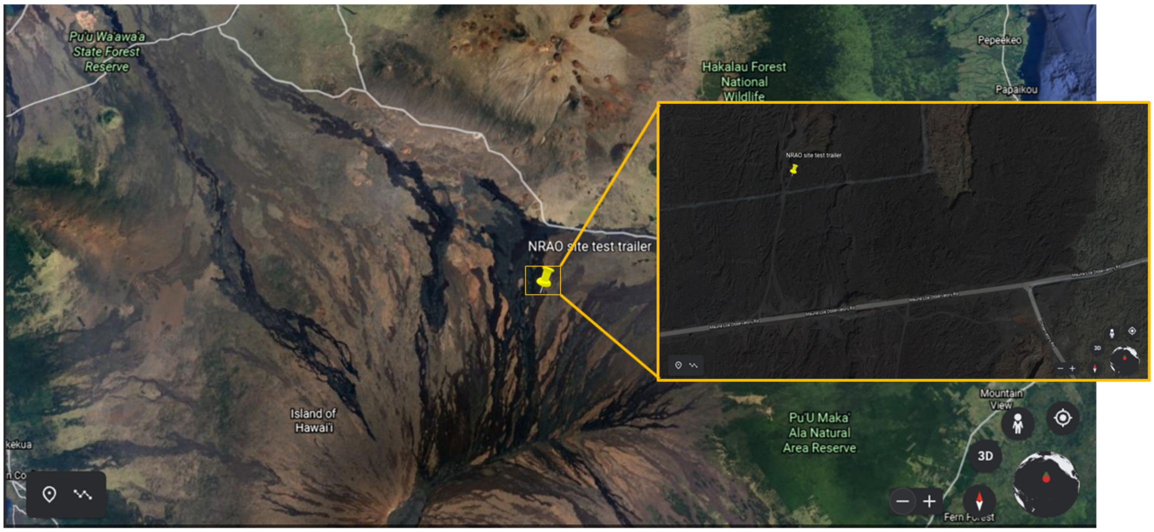

Figure 3: The larger map shows the approximate location of the PWS on the island of Hawai‘i. The inset shows the approximate location of the PWS with respect to the PTA fence and the nearby roads. Map images from Google Maps.

- Minimum and maximum battery voltage
- Minimum and maximum datalogger temperature
- Minimum and maximum solar pyranometer temperature
- Minimum and maximum positions of the solar pyranometer (x, y, and z)

All of the data were stored on the datalogger until downloaded by the LoggerNet software. Downloaded data were appended to .dat files on the LoggerNet control computer.

6 PTA Deployment

The PWS was deployed on PTA property on 2022 August 18. It was located near the southern fenceline. Figure 3 shows a map of the site location. The initial indication was that the cellular connection was reasonably strong and data collection began immediately after deployment.

The deployment at PTA is divided into 4 phases:

- Phase 1: 2022 August 18 to 2022 August 28
- Phase 2: 2022 August 29 to 2022 September 27
- Phase 3: 2022 September 28 to 2022 October 20
- Phase 4: 2022 October 21 to 2022 December 05

6.1 PTA: Phase 1

From 2022 August 18 to 2022 August 28, the PWS functioned fairly well. During this time, the datalogger was set to record values from the sensors once every five minutes, with the exception of the security camera which only recorded one image every hour. However, the retrieved data would sometimes have not-a-number (NAN) values recorded for some measurements. These instances of NAN values appeared to occur regularly, once per hour, for several hours, and would then go away. No obvious pattern emerged and no causes for the NAN values could be found.

6.2 PTA: Phase 2

From 2022 August 29 to 2022 September 27, the datalogger was set to record values from the sensors once every minute. Again, the security camera was the exception, recording one image every hour. During this time, more NAN values appeared in the data. It became increasingly obvious that something was wrong with the datalogger. We uploaded new control scripts, but they did not fix the problem.

6.3 PTA: Phase 3

From 2022 September 28 to 2022 October 20, the datalogger was recording so many NAN values that the data became completely unusable. Even those sensors which did not record NAN values were giving suspicious data. No analysis was performed on weather data during this time period. Only the security camera images were worth investigating during this phase. We uploaded new firmware to the datalogger in hopes of fixing the problem, but it did not work. The MK VLBA site technicians visited the PWS and check electrical connections and attempted various fixes, but nothing worked.

6.4 PTA: Phase 4

On 2022 October 21, NRAO staff participated in a telecon with Campbell Scientific staff to attempt to diagnose and fix the problems with the PWS datalogger. Campbell Scientific staff were able to determine that addresses in the datalogger for many of the sensors (the three temperature & humidity sensors, and the solar pyranometer) were all incorrect. It is unclear how those addresses changed in the datalogger. It was also discovered that the time the datalogger waited for incoming data to arrive was likely too short.

After the sensor addresses were corrected and the data collection wait times were increased, the PWS began functioning again. From 2022 October 21 to 2022 December 05, the PWS recorded data from the sensors every 5 minutes, and took an image with the security camera once each hour. No NAN values were present in the data during this time.

The Mauna Loa volcano began erupting on 2023 November 28 at approximately 09:30 UT. This is towards the end of Phase 4 of our PTA deployment. The impact of the eruption will be discussed in more detail in subsequent sections.

7 Results from PTA

Data from Phases 1, 2, and 4 were analyzed to determine if the PTA site was a suitable location for a radio telescope. All of the data collected are stored on NRAO machines which are regularly backed up. Access to the data may be arranged by contacting the authors.

7.1 Weather Condition Classifications

We defined 4 levels of weather conditions: "Good", "Questionable", "Poor", and "Very Poor". The levels were based on current VLBA operational constraints for high frequency (> 12 GHz) observations. Weather conditions were considered "Good" unless they fell into one of the other categories, as detailed in Table 2.

Table 2: Weather Condition Classifications

"Questionable"	"Poor"	"Very Poor"
Light Rain (single tip)	Light Rain (single tip)	Moderate or Heavy Rain (2 tips or more)
Max Wind Speed > 9 m/s	Max Wind Speed > 13.4 m/s	Max Wind Speed > 24.5 m/s
Avg. Air Temp. $< -10°$C	Avg. Air Temp. $< -17.8°$C	Avg. Air Temp. $< -10°$C
Avg. Air Temp. within 2°C of Avg. Dew Point	Avg. Air Temp. within 0.5°C of Avg. Dew Point	Min. Air Temp $<$ Max. Dew Point
Avg. Relative Humidity $> 50\%$	Avg. Relative Humidity $> 80\%$	Avg. Relative Humidity $= 100\%$

Note that both “Questionable” and “Poor” have the same rain fall condition. The American Meteorological Society classifies rain fall in 3 categories: Light (up to 2.5 mm per hour), Moderate (2.6 to 7.6 mm per hour), and Heavy (more than 7.6 mm per hour). Using five minute measurement intervals, we used estimates of: Light (up to 0.21 mm in five minutes), moderate (0.21 to 0.63 mm in five minutes), and Heavy (more than 0.63 mm in five minutes) We would have preferred to set a lower rain fall limit of “Slight Rain” for “Questionable”, but the rain gauge only allowed for measuring 0.254 mm of rain per tip which is already in the “Light Rain” category.

Weather conditions were classified for each time bin with reliable data.

Because these weather constraints are based on the current operating procedures of the VLBA, they should apply to any future candidate site (island or otherwise). They are intended to serve as objective criteria used to grade the candidate site location based on the weather data collected. However, the candidate site viability should be considered relative to general location and in comparison to local alternative candidates. For example, if it is determined that an ngVLA site in Florida is necessary, it may not be possible to find a location where the relative humidity is ever below the “Questionable” threshold; but several sites in Florida should be considered and the weather data collected at each would be useful in determining the preferred site for that region.

7.2 Results: Phase 1

Date Range: 2022-08-19 to 2022-08-28

During the relatively short Phase 1 time period, the PWS collected data once every five minutes. The resulting weather conditions were:

- Only 16.04% of times during Phase 1 were considered “Good”.
- 83.96% of times during Phase 1 were considered “Questionable” or worse.
    - 33.22% of times during Phase 1 were considered “Poor” or “Very Poor”.
    - 6.62% of times during Phase 1 were considered “Very Poor”.

The most common reason for a “Questionable” or a “Poor” flag was the relative humidity. The most common reason for a “Very Poor” flag was the air temperature being below the dew point.

The air temperature, dew point, and relative humidity data from Phase 1 are presented in Figure 4. One feature to note is that the dew point is frequently very close to (and sometimes above) the air temperature. Also, the relative humidity reached 100% several times.

The barometric pressure, solar irradiance, and rain total for Phase 1 are plotted in Figure 5. The solar irradiance has a low feature once per day when the shadow from the PWS structure falls on the pyranometer sensor. The rain total shows a large spike early in the deployment, which was not real; the MK site technicians poured water into the rain gauge to test it.

The wind speed data for Phase 1 are plotted in Figure 6. It shows that the winds for this time range were variable, but not often in excess of 13.4 m/s (30 mph), which is the threshold for “Poor” wind conditions.

Figure 7 shows the weather conditions as a function of time for Phase 1. Each data point represents a single five-minute collection period. Even for the relatively short period of time covered by this phase, it is evident that the weather are not often favorable for high-frequency observations.

7.3 Results: Phase 2

Date Range: 2022-08-29 to 2022-09-27

During Phase 2, the PWS collected data once every minute. The resulting weather conditions were:

- Only 5.28% of times during Phase 1 were considered “Good”.
- 94.72% of times during Phase 1 were considered “Questionable” or worse.

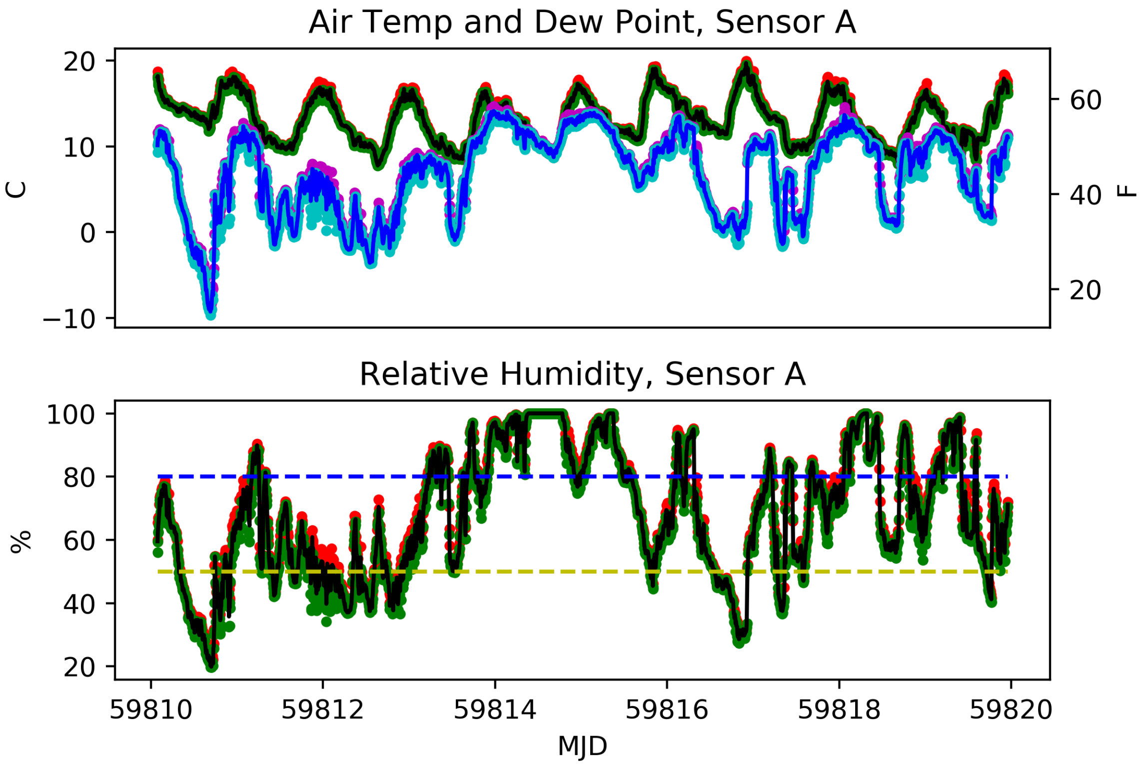

Figure 4: Data from the temperature and humidity Sensor A during Phase 1. Data from Sensors B and C were very similar. Top: Temperature (red=maximum, green=minimum, black=average) and dew point (magenta=maximum, cyan=minimum, blue=average) vs time in modified Julian days. Note that the dew point is often very close to the air temperature. Bottom: Relative humidity (red=maximum, green=minimum, black=average) vs time in modified Julian days. The yellow dashed line indicates the "Questionable" limit. The blue dashed line indicates the "Poor" limit.

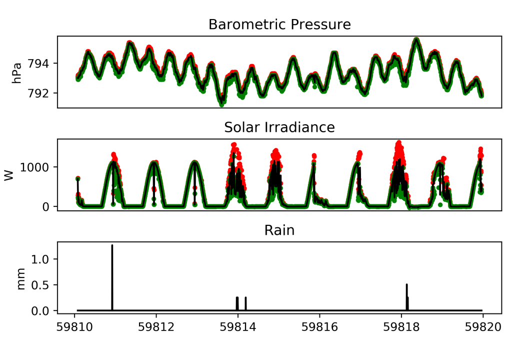

Figure 5: Data from the barometer, pyranometer, and rain gauge during Phase 1. Top: Barometric pressure (in hPa) vs time. Middle: Solar irradiance (in Watts) vs time. Bottom: Rain fall (in mm) vs time. For all plots, red=maximum, green=minimum, black=average.

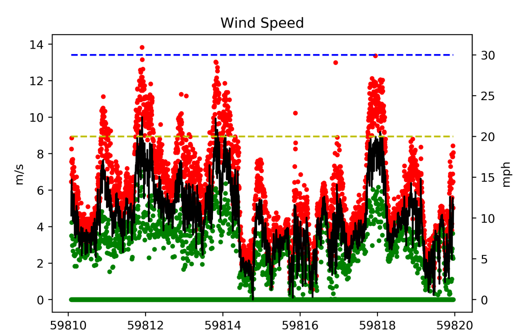

Figure 6: Wind speed measurements during Phase 1. Red=maximum, green=minimum, black=average. The yellow dashed line indicates the "Questionable" limit. The blue dashed line indicates the "Poor" limit.

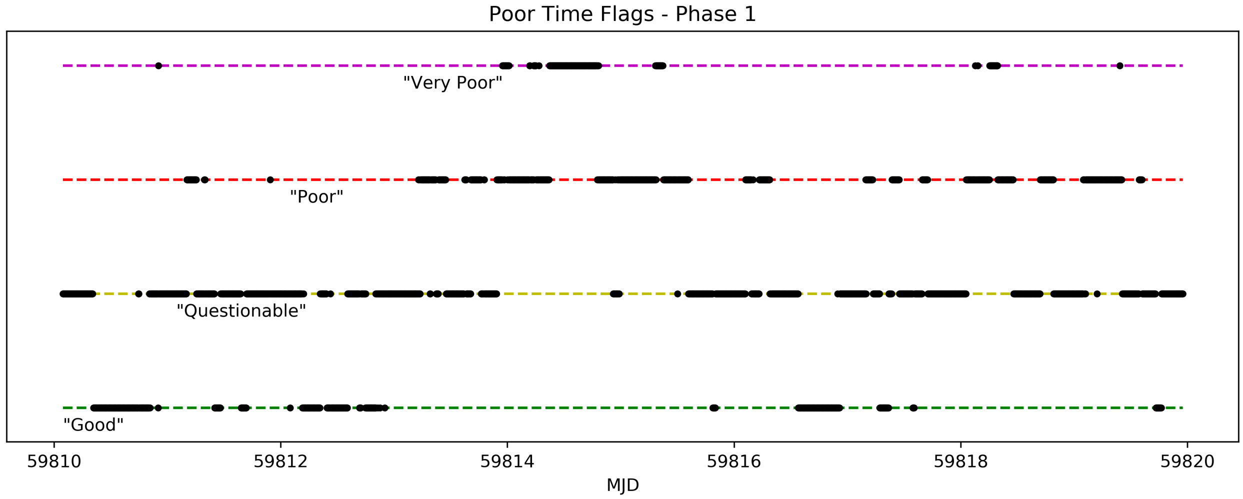

Figure 7: Weather conditions vs time for Phase 1

- 57.25% of times during Phase 1 were considered "Poor" or "Very Poor".
- 14.45% of times during Phase 1 were considered "Very Poor".

Just as in Phase 1, the most common reason for a "Questionable" or a "Poor" flag was the relative humidity and the most common reason for a "Very Poor" flag was the air temperature being below the dew point.

The air temperature, dew point, and relative humidity data from Phase 2 are presented in Figure 8. One feature to note is that the dew point is frequently very close to (and sometimes above) the air temperature. As in Phase 1, the relative humidity reached 100% several times, sometimes staying at 100% for significant stretches of time. In fact, the low humidity ($< 50\%$) times are clear outliers in this figure.

The barometric pressure, solar irradiance, and rain total for Phase 2 are plotted in Figure 9. The solar irradiance again has an obvious low feature once per day when the shadow from the PWS structure falls on the pyranometer sensor. The rain total plot shows several times where the bucket tipped in subsequent or nearby measurement times. The rain fall could have been in the "moderate" range, which would cause a "Very Poor" weather condition flag. However, we did not base the rain condition flag on adjacent data, only single tips. So, the weather conditions could be slightly worse than reported here (i.e., "Very Poor" due to rain more often than reported).

The wind speed data for Phase 2 are plotted in Figure 10. It shows that the winds for this time range were variable, but generally not as strong as during Phase 1. Only one day had wind speeds in excess of 13.4 m/s (30 mph), which is the threshold for "Poor" wind conditions.

Figure 11 shows the weather conditions as a function of time for Phase 2. Each data point represents a single one-minute collection period. As with Phase 1, the weather are not often favorable for high-frequency observations.

7.4 Results: Phase 3

Date Range: 2022-09-28 to 2022-10-20

As discussed previously, no data from this phase were analyzed due to the high number of NAN values recorded. All data from this phase are considered unreliable. The security camera was still functioning and frequently showed fog during the day.

7.5 Results: Phase 4

Date Range: 2022-10-21 to 2022-12-05

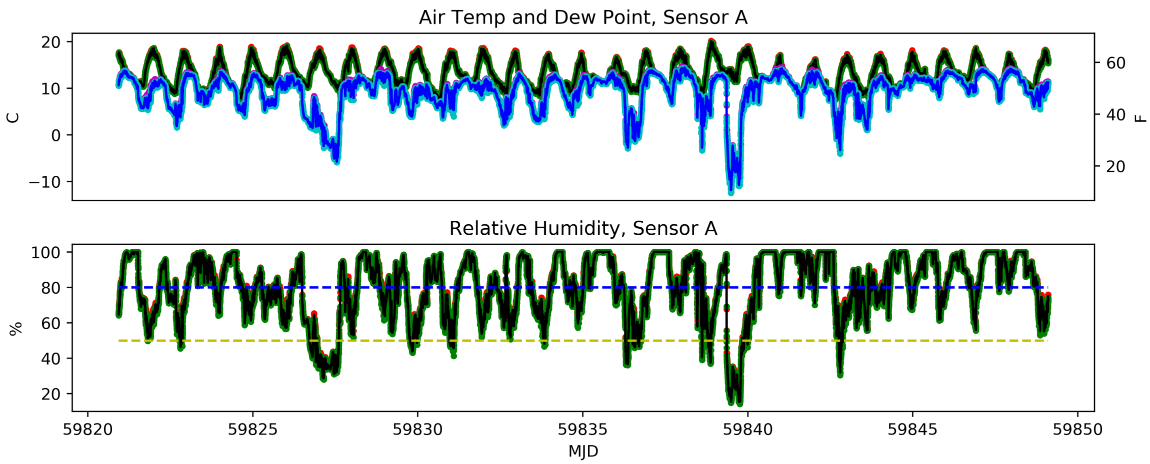

Figure 8: Data from the temperature and humidity Sensor A during Phase 2. Data from Sensors B and C were very similar. Top: Temperature (red=maximum, green=minimum, black=average) and dew point (magenta=maximum, cyan=minimum, blue=average) vs time in modified Julian days. Note that the dew point is often very close to the air temperature. Bottom: Relative humidity (red=maximum, green=minimum, black=average) vs time in modified Julian days. The yellow dashed line indicates the "Questionable" limit. The blue dashed line indicates the "Poor" limit.

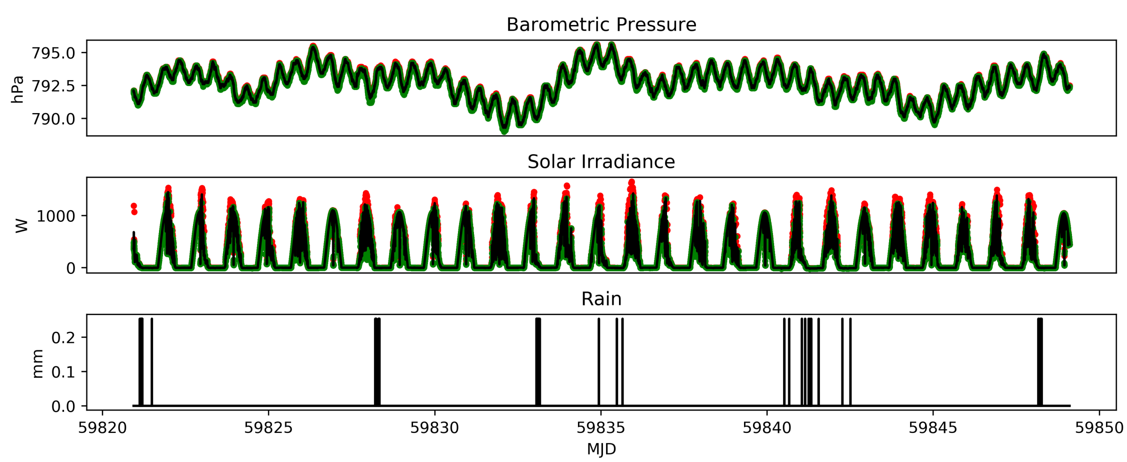

Figure 9: Data from the barometer, pyranometer, and rain gauge during Phase 2. Top: Barometric pressure (in hPa) vs time. Middle: Solar irradiance (in Watts) vs time. Bottom: Rain fall (in mm) vs time. For all plots, red=maximum, green=minimum, black=average.

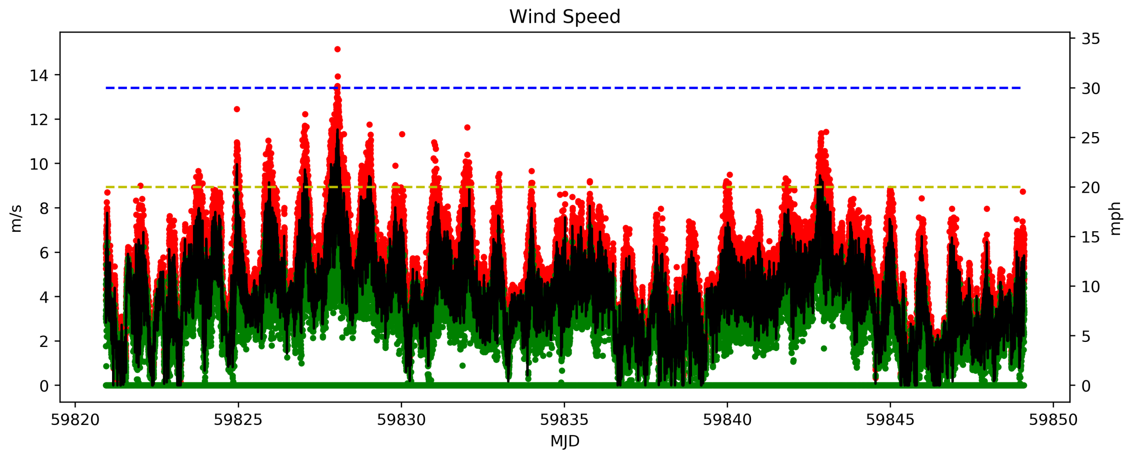

Figure 10: Wind speed measurements during Phase 2. Red=maximum, green=minimum, black=average. The yellow dashed line indicates the "Questionable" limit. The blue dashed line indicates the "Poor" limit.

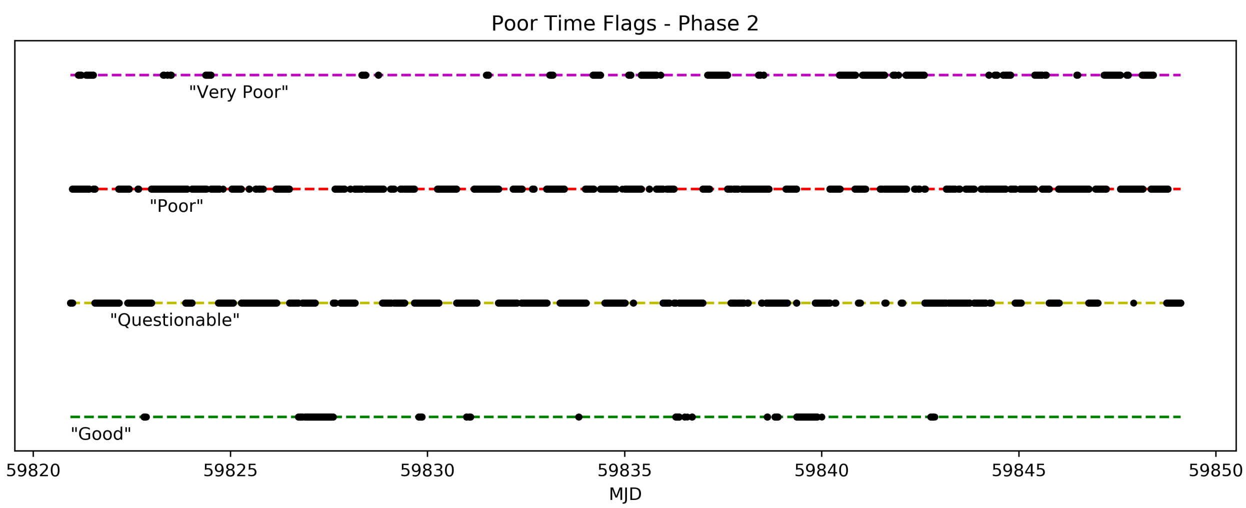

Figure 11: Weather conditions vs time for Phase 2

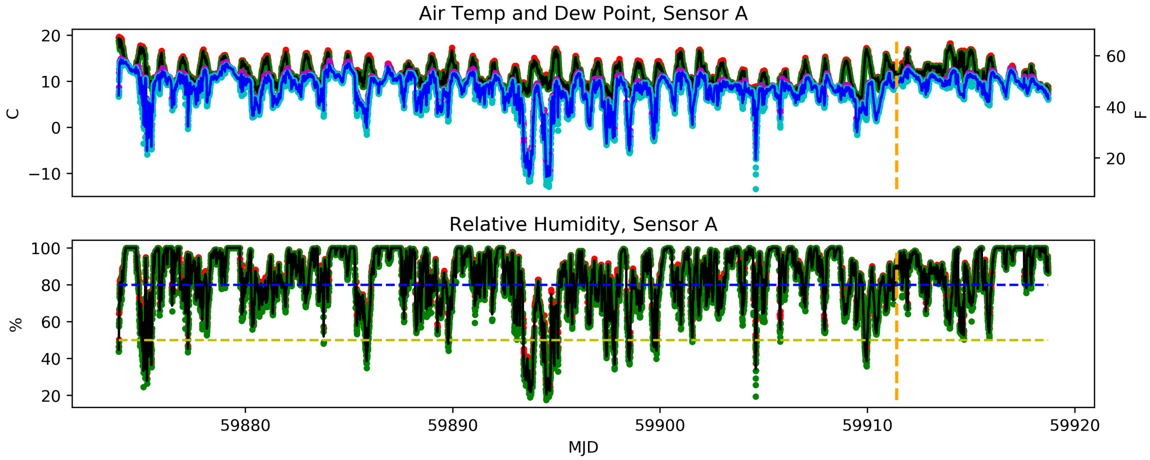

Figure 12: Data from the temperature and humidity Sensor A during Phase 4. Data from Sensors B and C were very similar. Top: Temperature (red=maximum, green=minimum, black=average) and dew point (magenta=maximum, cyan=minimum, blue=average) vs time in modified Julian days. Note that the dew point is often very close to the air temperature. Bottom: Relative humidity (red=maximum, green=minimum, black=average) vs time in modified Julian days. The yellow dashed line indicates the “Questionable” limit. The blue dashed line indicates the “Poor” limit. The vertical orange dashed line indicates when the Mauna Loa eruption began.

This is the longest phase in this report. During Phase 4, the PWS collected data once every five minutes. The resulting weather conditions were:

- Only 3.55% of times during Phase 1 were considered “Good”.
- 96.45% of times during Phase 1 were considered “Questionable” or worse.
    - 69.46% of times during Phase 1 were considered “Poor” or “Very Poor”.
    - 20.01% of times during Phase 1 were considered “Very Poor”.

Once again, the most common reason for a “Questionable” or a “Poor” flag was the relative humidity and the most common reason for a “Very Poor” flag was the air temperature being below the dew point.

The eruption of Mauna Loa occurred during this phase. Plots of the weather data have a vertical orange dashed line to indicate the start of the eruption.

The air temperature, dew point, and relative humidity data from Phase 4 are presented in Figure 12. One feature to note is that the dew point is frequently very close to (and sometimes above) the air temperature. As in Phases 1 and 2, the relative humidity reached 100% several times, sometimes staying at 100% for significant stretches of time. Low humidity ($< 50\%$) times were again a relatively rare occurrence.

The barometric pressure, solar irradiance, and rain total for Phase 4 are plotted in Figure 13. The solar irradiance again has an obvious low feature once per day when the shadow from the PWS structure falls on the pyranometer sensor. It is unclear why the pyranometer occasionally reported negative irradiance values. It is also unclear why the irradiance values appeared to climb at the end of this phase, but it could be related to lava from the Mauna Loa eruption getting nearer to the PWS. The rain total plot shows several times of “Moderate” or heavier rainfall (2 or more tips of the bucket in a five-minute interval).

The wind speed data for Phase 4 are plotted in Figure 14. Again, the wind speeds are variable but generally not above the 12.4 m/s (30 mph) threshold.

Figure 15 shows the weather conditions as a function of time for Phase 4. Each data point represents a single five-minute collection period. As with Phases 1 and 2, the weather are not often favorable for high-frequency observations. In fact, this time period had the highest percentage of “Poor” and “Very Poor” conditions.

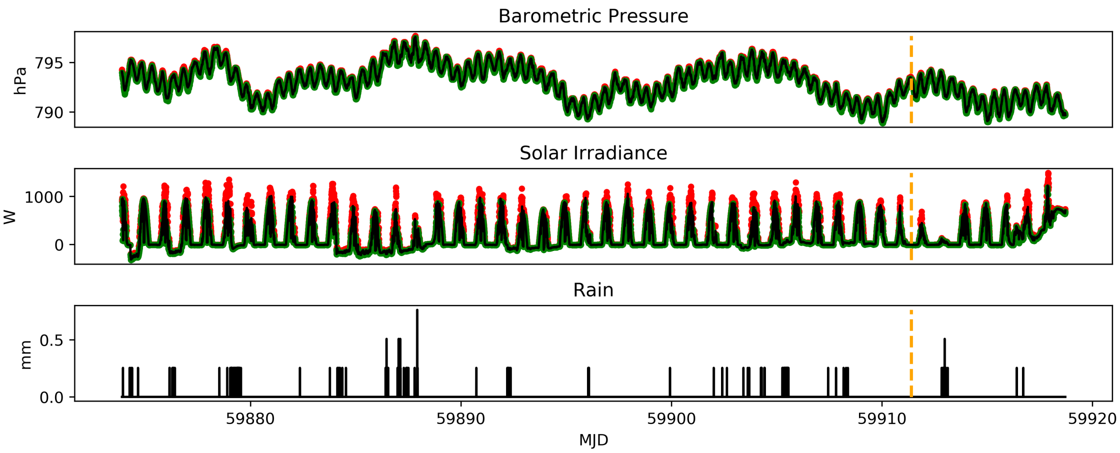

Figure 13: Data from the barometer, pyranometer, and rain gauge during Phase 4. Top: Barometric pressure (in hPa) vs time. Middle: Solar irradiance (in Watts) vs time. Bottom: Rain fall (in mm) vs time. For all plots, red=maximum, green=minimum, black=average. The vertical orange dashed line indicates when the Mauna Loa eruption began.

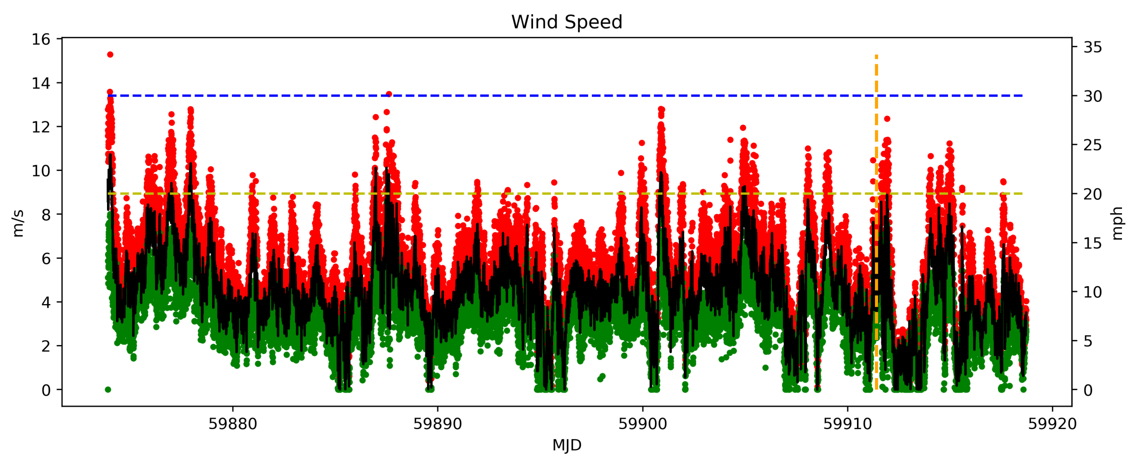

Figure 14: Wind speed measurements during Phase 4. Red=maximum, green=minimum, black=average. The yellow dashed line indicates the “Questionable” limit. The blue dashed line indicates the “Poor” limit. The vertical orange dashed line indicates when the Mauna Loa eruption began.

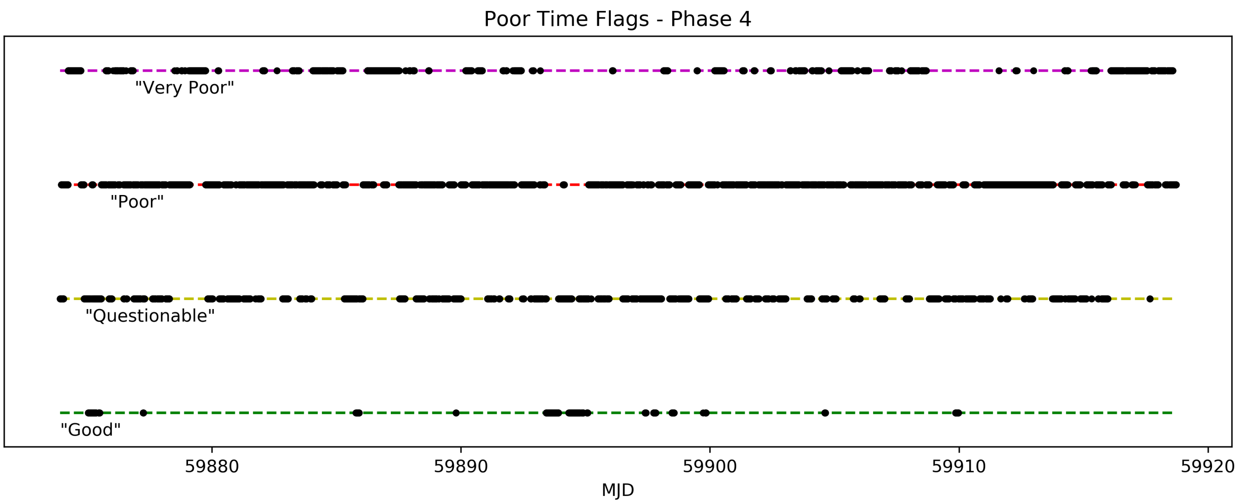

Figure 15: Weather conditions vs time for Phase 4.

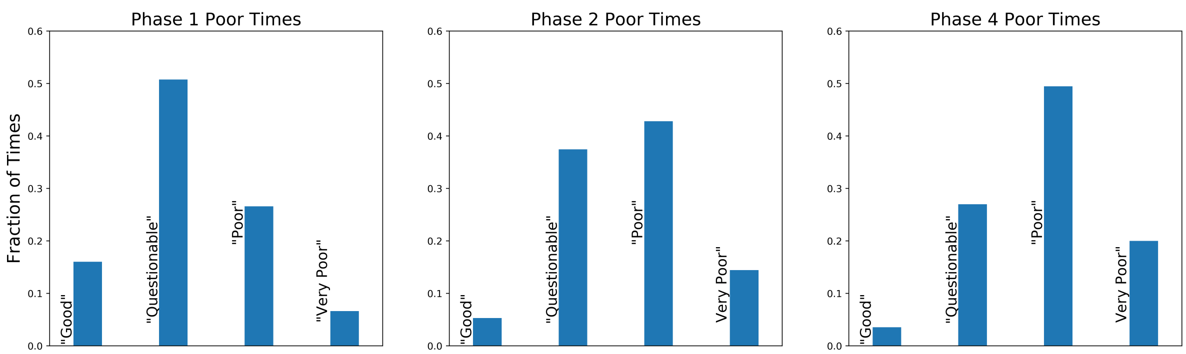

Figure 16: Histograms for the weather conditions for each of the phases. Note that the conditions were very rarely "Good".

7.6 Overall Weather Conditions at PTA

The weather conditions for the PTA site are summarized in Figure 16. From these histograms, and the data presented in the previous sections, it is obvious that the PTA site does not often have good weather for high-frequency observations. In particular, the relative humidity at the site is almost constantly above the 50% threshold that we use for "Questionable" weather conditions, and is frequently above the 80% threshold for "Poor" weather.

In addition to the quantitative weather data, we also looked at the images from the security camera to get qualitative information about things like cloud cover and fog. The images should heavy fog present on most days.

The high humidity and frequent fog make the PTA site unsuitable for a radio telescope.

8 Mauna Loa Eruption

The Mauna Loa volcano began erupting at about 09:30 UT on 2022 November 28th. The lava flows quickly shifted to the northeast side of the volcano, which was in the direction of the PTA site. The lava flows crossed Mauna Loa Observatory Road on November 29th. NRAO was informed that we would not be able to access the PWS at that time. It is estimated that the lava came within approximately 4500 feet (1.37 km) of the PWS. In fact, images taken by the security camera the morning of 2022 December 01 clearly show a glow from the nearby lava flow.

The VLBA MK site technicians were given special permission by PTA to recover the PWS on 2022 December 05. PTA provided a security escort to ensure the safety of NRAO staff while they disassembled and removed the PWS.

9 Lessons Learned

1. It is important to carefully inspect the sensors when mounting them and ensure that all packing material has been removed.

2. The PWS functioned fairly well, but the datalogger had problems. Contact with the Campbell Scientific staff was essential to fixing these problems. Purchasing quality components from a reliable retailer with good customer service should be a high priority for any future projects similar to the PWS.

3. Prior to deploying the PWS, candidate locations should be evaluated with threshold criteria for viability, including land use, natural hazards, and other unacceptable risk.

4. It is crucial to have NRAO staff, in this case the VLBA MK site technicians, who can reliably access the PWS and perform occasional checks and repairs.

10 Conclusions

The PTA site was initially promising, but it soon became apparent that the weather conditions were not suitable for a radio telescope, especially one that intends to operate at frequencies > 12 GHz. The eruption of Mauna Loa, and the proximity of the resulting lava flows, provided an incontrovertible reason to avoid building a radio telescope at the PTA site.

11 Acknowledgments

NRAO thanks the staff at PTA for their assistance with deploying the PWS on their property. In particular, we appreciate the communication with the VLBA MK site technicians throughout the Mauna Loa eruption, and providing aid in recovering the station.

NRAO thanks the user support staff at Campbell Scientific for their assistance with correcting the datalogger issues.

The authors thank the VLA mechanical and engineering staff for their assistance with modifying the PWS trailer, installing and testing the mast, and painting the PWS. Additional thanks to Jon Thunborg and Mike Romero for their assistance with calculating the wind loading of the PWS and designing the support wire structure.

The authors thank Jim Ogle, Anthony Sowinski, and Paul Dyer for their input on VLBA scheduling and weather constraints.