LOW-COST
REMOTE WEATHER INFORMATION SYSTEM
PHASE I AND PHASE 2

FINAL PROJECT REPORT
INE/AUTC 18.14

by

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16. Abstract
Remote weather information systems (RWIS) are an important part of determining maintenance activities and scheduling. However, the cost of RWIS limits the number of systems that can be deployed. Because of the lack of power and the high power budget of commonly used systems, some locations are not suitable for RWIS even though the information would be of great value. This project focused on the development of a low-cost, low-power RWIS that is suitable for remote locations and allows for a higher density of RWIS units. The system produced under this study uses less than 10 watts of power and costs less than $10,000 for the basic system. The system has performed well in Fairbanks, Alaska, over two winters. In addition, the system has been fully integrated into the Alaska Department of Transportation and Public Facilities RWIS network.

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Abstract

Remote weather information systems (RWIS) are an important part of determining maintenance activities and scheduling. However, the cost of RWIS limits the number of systems that can be deployed. Because of the lack of power and the high power budget of commonly used systems, some locations are not suitable for RWIS even though the information would be of great value. This project focused on the development of a low-cost, low-power RWIS that is suitable for remote locations and allows for a higher density of RWIS units. The system produced under this study uses less than 10 watts of power and costs less than $10,000 for the basic system. The system has performed well in Fairbanks, Alaska, over two winters. In addition, the system has been fully integrated into the Alaska Department of Transportation and Public Facilities RWIS network.

1. Introduction

Remote weather information systems (RWIS) have become an important data source for departments of transportation (DOTs) to use in managing their highway networks and to help the traveling public make travel decisions. RWIS and mobile weather data acquisition systems provide data that are in turn used to improve weather prediction algorithms. DOTs also use systems such as Maintenance Decision Support Systems (MDSS) to plan snow and ice control activities before storms. Like many state DOTs the Alaska Department of Transportation and Public Facilities (DOT&PF) has successfully implemented MDSS, which has allowed maintenance and operations forces to plan for winter storms rather than react to them. Between 10 percent and 20 percent savings can be realized by using anti-icing in combination with RWIS data (Goselly, 2001).

Typical RWIS sites use between 25 watts and 150 watts unless heaters are needed, as is common in northern tier states, which can raise the power budget considerably (Wies, 2017). Wies noted that a 786 watts/day is not uncommon for daylight winter conditions.

The DOT&PF implemented a program of collecting weather data with a mobile weather data collection system provided by WeatherCloud, Inc in order to improve the weather algorithms used in its MDSS. The system collects air temperature, pavement temperature, relative humidity, location, vehicle speed, and vehicle direction at a cost of $1,250 per unit installed (includes cost of cell phone and sensors) and $1,250 per year for the licensing fee. The licensing fee includes data collection and forwarding to MDSS and the cellular data fees. WeatherCloud was contacted to determine whether these low-cost multiple sensor devices could be integrated into a low-cost, low-power RWIS. The desire was not necessarily to replace existing RWIS but to use the technology to augment existing systems and to inexpensively increase the density of RWIS units.

If the initial cost could be decreased, the power requirements reduced, and communications problems resolved, then the density of RWIS could be increased significantly. To address these challenges the Alaska University Transportation Center (AUTC) partnered with WeatherCloud, Inc. to develop a low-cost, low-power RWIS that meets the requirements of DOTs. The design goals were as follows:

- Keep the cost of a basic system with air temperature, roadway temperature, relative humidity, and wind speed under $10,000, including mounting hardware but excluding power systems.
- Reduce the power budget to around 10 watts.
- Address communications in remote areas.
- Use a modular approach that allows a variety of power and communication systems to accommodate the addition of future sensors.
- Simplify installation such that the skills required are minimal.
- Simplify maintenance to plug and play.
- Include remote diagnostics for troubleshooting.

2. System Design

Figure 2.1 shows a block diagram of the system. The system was designed to use 12 volts so that several power sources, including solar, wind, or line power, could be used. A battery is used to buffer the system from power outages for several days. If longer power outages are anticipated, the battery capacity can be increased. This can be very helpful in Alaska, where solar energy may not be available during the months of December and January.

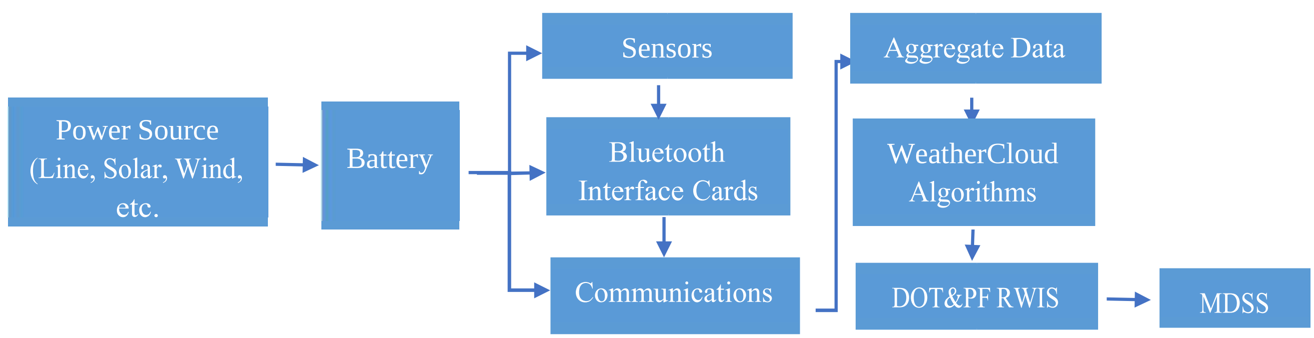

Figure 2.1 System flow diagram

In keeping with the design goals, designers chose to focus on low-cost, low-power sensors, borrowing from the mobile systems. The initial design provided the following sensors:

- Air temperature: accurate to 0.1 Celsius
- Infrared ground temperature measurements: scan across a 60° angle; accurate to 0.1 Celsius at 1 Hz
- Cup and vane wind speed and direction or acoustic wind speed and direction
  - Anemometer: operating range -40 to 50 Celsius, max sampling speed is 1 hz
  - Wind speed: range from 0–30 m/sec, resolution 0.01 m/s, accuracy 0.3 m/x or <3 percent, whichever is larger

    - Wind direction: range from 0–359 degrees
- Relative humidity: polymer capacitive sensing, accurate to at least +/- 3 percent across 10 pecent to 90 percent
- Battery output/charge: volts/percent
- Solar radiation: visible light intensity 300 nm to 1100 nm, 0.001 to 1 K uW/cm^2
- Snow depth monitoring: acoustic sensor.

Designers chose to communicate via low power Bluetooth 4.0 between the sensor and a cell phone. This provides an opportunity to wirelessly mount the sensor up to 30 ft distant, which can prove advantageous for measuring pavement temperature and snow depth.

All sensors and the control box can be mounted to a light pole, sign post, or other available pole with minimal hardware. As indicated, sensors can be mounted on poles some distance away from the control box, provided that power is available for each sensor.

Communications for this system uses a cell phone with an app that reads the data and forwards them to the WeatherCloud data system, WeatherMesh. The app is designed such that it can be upgraded remotely, and the sensor connection can be refreshed at any time. This is intended to reduce the number of visits to the site for repair and to provide monitoring of the system. However, if cell coverage is not available, other communication systems such as VHF or UHF radio systems or satellite communications can be used. It is possible to repeat data through multiple RWIS if desirable.

Once the data have been transmitted to the WeatherCloud database, the data are passed through a set of algorithms to filter out data that are not reasonable, such as being out of range. This is done to ensure that data quality is maintained. If the data are unreasonable over time, staff are notified so that corrective action can be taken. WeatherCloud maintains the data in its database for future review and analysis.

Data are then fed into the DOT&PF RWIS, MDSS or other systems for public use. The department also maintains historical data in its database.

The modular design of the system allows for a range of configurations to meet specific conditions.

3. Installation

The new RWIS was collocated with existing RWIS to allow comparisons of the new sensors with proven systems. The first system was located at Cowles and Lathrop Streets in Fairbanks, Alaska. The second was located at Badger Road and Elvira Street near North Pole, Alaska.

It was decided that line power would be used to charge a battery for the first systems. This would simulate the use of solar or wind energy to charge the battery, should the system be moved to a location without line power.

Installation took less than 2 hours at each site, including setting up communications. The installed system at Cowles Street is shown in the photo in figure 3.1, including the sensor and electronic box mounting. Figure 3.2 shows the sensor-Bluetooth interface cards, which provide communications between the sensor and the cellphone. The interface cards are prototype cards and are simply mounted with Velcro. These cards are easily adapted to other sensors.

Figure 3.1 Cowles Street installation

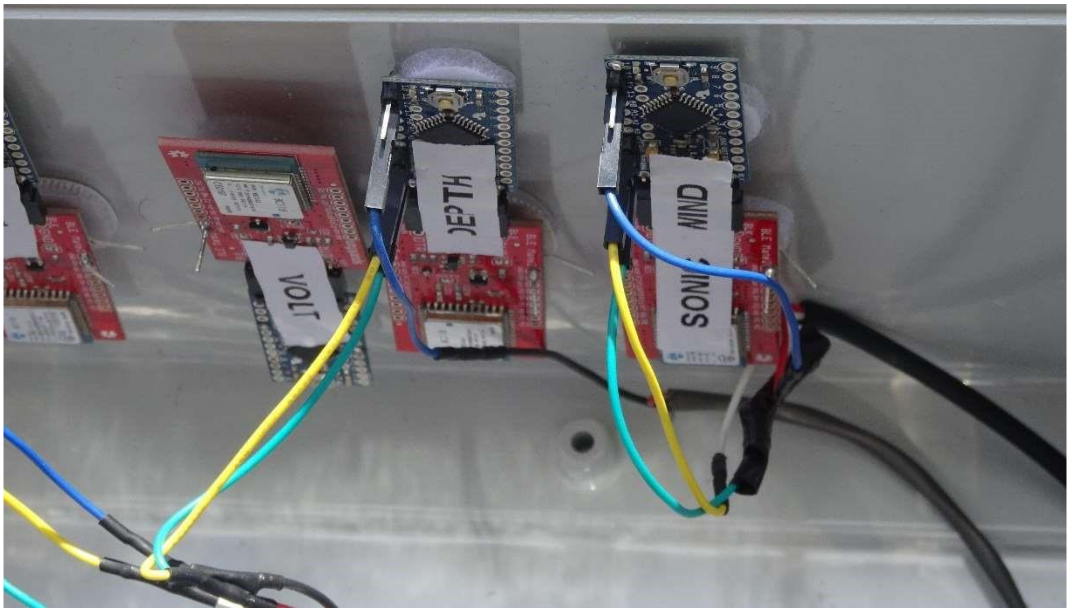

Figure 3.2 Prototype Bluetooth interface cards

4. Performance

The system served two years at both the Cowles site and the Elvira site. During that time there were two outages. The first occurred after a power outage when the ground-fault tripped. The system detected low battery voltage, which triggered a warning. Resetting the ground-fault rectified the problem.

The anemometer failed during the second winter because of a failed Bluetooth card. The card was replaced by a WeatherCloud technician. WeatherCloud decided to have its technician repair the system while in Fairbanks for other work. However, the repair could have been easily carried out by local personnel.

Data from the WeatherCloud RWIS were compared with the DOT&PF RWIS data at the Cowles site, as shown in Figure 4.1. Unfortunately, data during the coldest months were not available from DOT&PF. However, the WeatherCloud data were generally within 2° Celsius of the temperature from the available DOT&PF RWIS. The system worked reliably during the coldest winter temperatures.

Windspeed data were similar to those reported by DOT&PF. Note that the WeatherCloud anemometer was positioned considerably lower than the DOT&PF anemometer. Consequently, there may have been some influence from traffic on the data reported by WeatherCloud. The anemometer continued to work during the coldest months.

Although not shown, the WeatherCloud relative humidity tended to be slightly lower than the DOT&PF data. Measuring relative humidity at cold temperatures is quite difficult, especially with low cost sensors.

There were no outages at the Badger-Elvira site over the past two years.

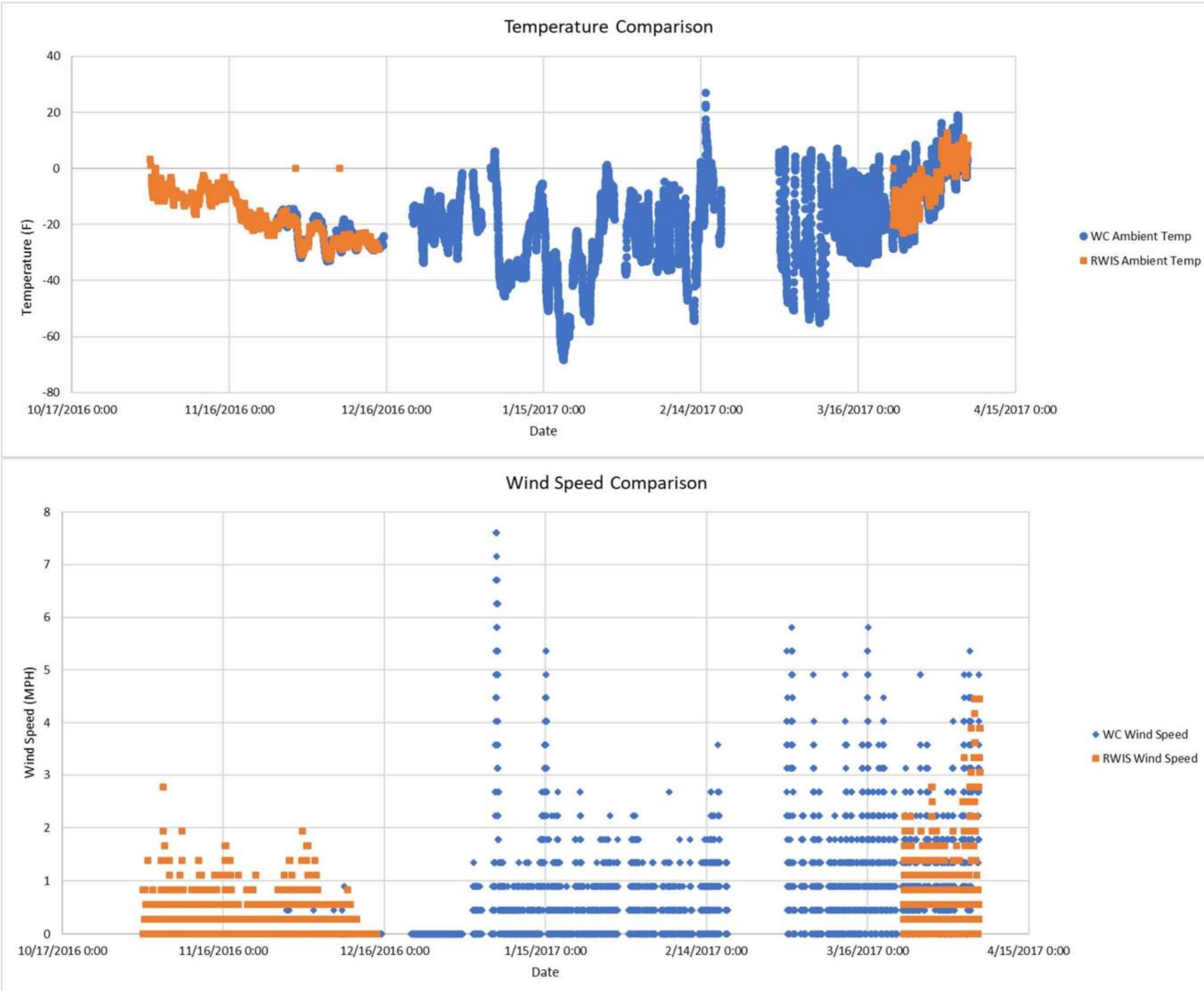

Figure 4.1 Temperature and wind speed data comparison

5. Integration into the DOT&PF RWIS

The DOT&PF has a robust RWIS. Consequently, if the WeatherCloud RWIS is to be useful, it must be able to be integrated into the DOT&PF RWIS. The DOT&PF assisted in integrating the WeatherCloud RWIS into its system to test the new system. The integration required little effort beyond what was expected with the addition of any new system. A few discussions were required to ensure the data were fully compatible and that data quality was acceptable. In the end, the required changes to the data were minor, mostly to achieve unit compatibility and frequency compatibility. Figure 5.1 shows the Badger-Elvira system's reports from the DOT&PF RWIS site at nearly the same time. The data reported were quite close. The differences were likely due to differences in sensor location and differences in data collection times. Wind direction likely required some adjustment in the mounting direction of the anemometer. As noted earlier, the relative humidity reported by the WeatherCloud system was slightly lower than that reported by the DOT&PF system.

Badger Road @ Elvira Avenue

This camera has failed. We apologize for the inconvenience. A new one is on order.

For definitions, click on the name field.

Date / Time	
08/09/2018 12:50 PM	
Atmospheric Data	
Air Temperature	57 °F
Dew Point	40 °F
Relative Humidity	51 %
Wind Speed	Calm
Wind Direction	SW
Wind Speed Maximum	3 mph
Wind Direction of Maximum Speed	S

Latest Weather Cloud Data	
Date/Time	08/09/2018 1:04 PM
Latitude (degrees)	64.7719783
Longitude (degrees)	-147.3536798
Altitude (meters)	163 m
Air Temperature	59°F
Relative Humidity	47%
Station Barometric Pressure (non-aviation)	993.1 mb
Wind Speed	4 mph
Wind Direction	W

Figure 5.1 DOT&PF RWIS web interface

6. Discussion of Phase I RWIS

The Phase I RWIS was a prototype system intended to prove that an affordable system can be produced that will perform in the harsh environment of Alaska. The two systems discussed in this report met all the design requirements:

- The basic system can be produced for less than $10,000.
- The system uses just under 10 watts of DC power at 12 volts.
- While cell phones were used for these installations, satellite communications are viable. In addition, the system can implement a repeater network in which each installation acts to forward data from another system. The system can also use VHF or UHF radio to forward the data.
- The Bluetooth interface allows additional sensors to be added easily.
- The system shows any sensor failures and monitors the battery voltage.
- Repairs are easily made and can be made by persons with minimal expertise.
- The system easily integrates into Alaska's RWIS.

When the data were initially extracted, the quality of the data was low, requiring considerable manual review. It was found that collecting data too frequently caused buffer overflows, which in turn caused incomplete or corrupted data records. Reducing the frequency of data collection and adding software to check the quality of the data were found to improve the quality of the data dramatically. In consultation with DOT&PF, data collection intervals were established at 15 minutes to be consistent with its RWIS data collection interval.

Overall, the WeatherCloud RWIS met or exceeded the design criteria established by the team. As a result, it was decided to test the system in an even harsher climate using alternative communications and power systems.

7. Phase II Overview

On the basis of the Phase I results, the DOT&PF, the University of Alaska Fairbanks (UAF), and WeatherCloud decided to test the system further by placing a system on Eagle Summit, about 120 miles north of Fairbanks on the Steese Highway. The plan was to use the satellite Internet at Montana Creek Maintenance Camp and place a cellular-based transmitter/receiver system at the maintenance camp, a repeater at Twelve-Mile Summit, and a transmitter/receiver at Eagle Summit. Using a topographical map of the area, the radio frequency (RF) path appeared feasible. However, when the RF path was tested in the spring of 2017, the path was found to not exist. Although the use of satellite communications would have been the next best alternative, the project budget simply did not allow that alternative to be implemented. Therefore, it was decided to put a stand-alone system at Montana Creek Maintenance Station and use the wireless Internet as the communications interface.

The goals of this installation were as follows:

- Test solar and wind power systems.
- Test an alternative communication system.
- Test the system in an environment that is somewhat more severe than in Fairbanks.
- Prove the system is fully functional off-grid.

The design criteria were the same as those for Phase I. However, WeatherCloud was requested to provide a prototype, commercial ready system. The DOT&PF required that the system be integrated into its RWIS. The system provided was like the ones provided for Fairbanks, except that the system had been made commercial ready and included solar panels and wind generators. The communications system linked into the WiFi at Montana Creek.

The system was installed on April 26, 2018, inside the maintenance compound. Installation included clearing the site of snow by DOT&PF; placing the tripod mounting hardware; mounting the solar panels, wind generator sensors, and the control box; connecting wiring; establishing communications; and testing the system. Installation took a little over 4 hours. Figure 7.1 shows the installation. The system was mounted on a tripod to allow for easy relocation. The DOT&PF plans to move the system to the roadway sometime in the summer of 2019. The system was not placed on the roadway this year because of a lack of funding for communications. DOT&PF plans to extend WiFi in the maintenance buildings to cover the roadway just outside the camp.

Figure 7.1 Montana Creek installation

Unfortunately, the wind generator/solar panel regulator failed, forcing the system to be installed on battery power. The WeatherCloud technician returned the next day with a solar panel regulator, which allowed the solar panels to be connected. WeatherCloud later shipped a wind generator regulator to UAF for installation at a convenient time. While not planned, this did allow the collection of baseline data for a solar-powered system in the summer. Figure 7.2 shows the system voltage between May 1 and July 31, 2018. Note that the voltage never dropped below 12.5 volts, indicating that the panels were providing plenty of power for the system.

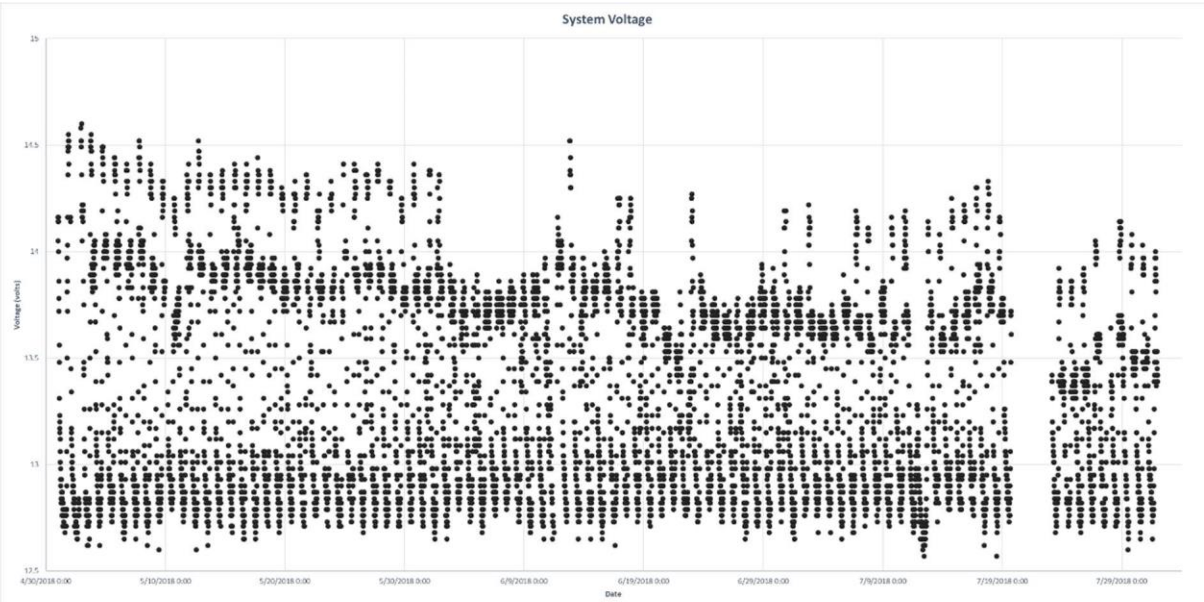

Figure 7.2 System voltage over the summer months

The lack of data around July 20th was due to the loss of Internet from a satellite outage (the satellite provides Internet to the Maintenance Camp). Otherwise, the system worked flawlessly.

Figures 7.3 through 7.8 show the data collected between May 1 and July 31, 2018. As with the first two sites, the data were recorded at 15-minute intervals. A review of the data showed that they were consistent with what was expected at this site.

As a side note, the roadway was treated with calcium chloride for dust management. Calcium chloride begins to lose its effectiveness below 35 percent relative humidity. By tracking the humidity as shown in figure 7.8, one can predict when the roadway may be dusty.

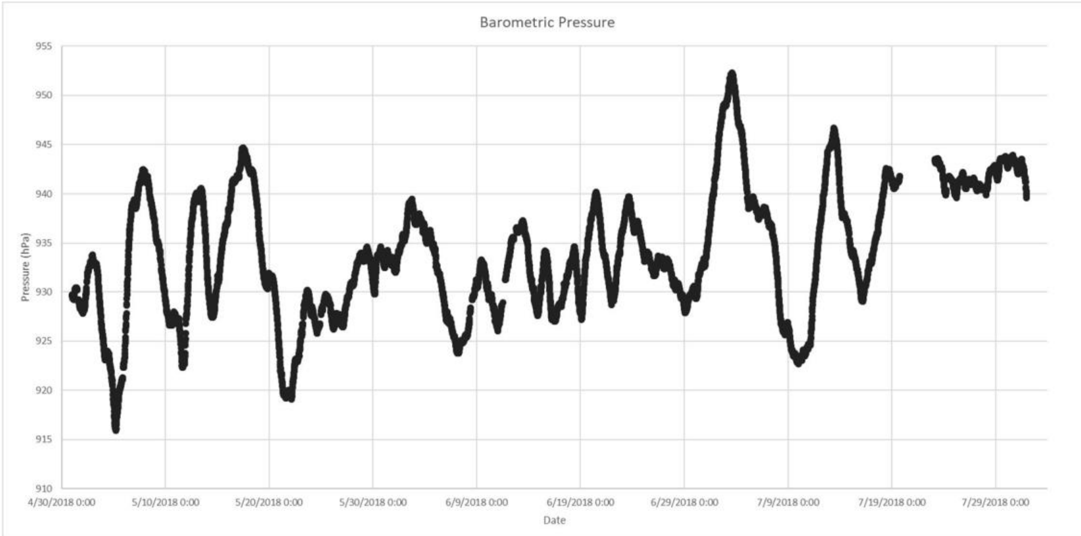

Figure 7.3 Barometric pressure

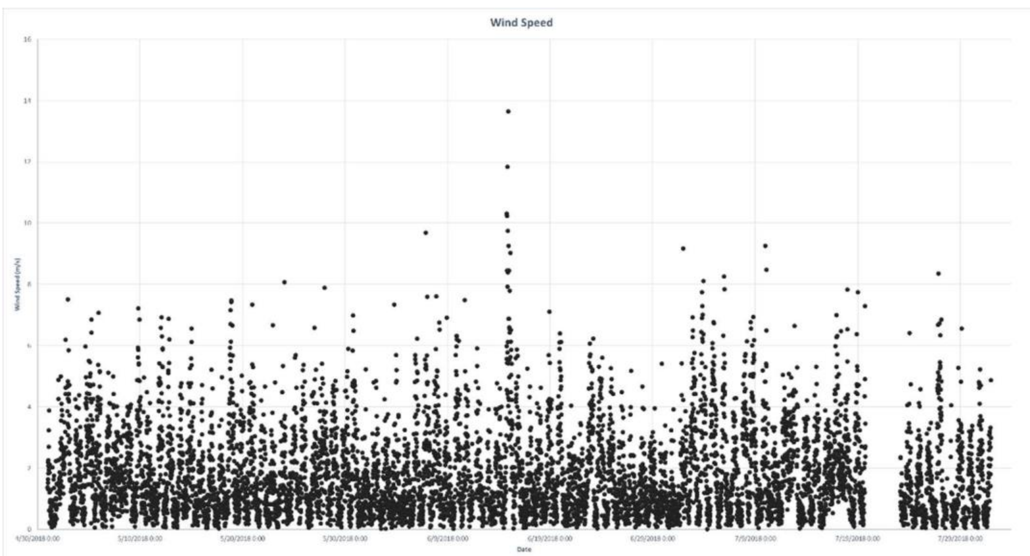

Figure 7.4 Wind speed

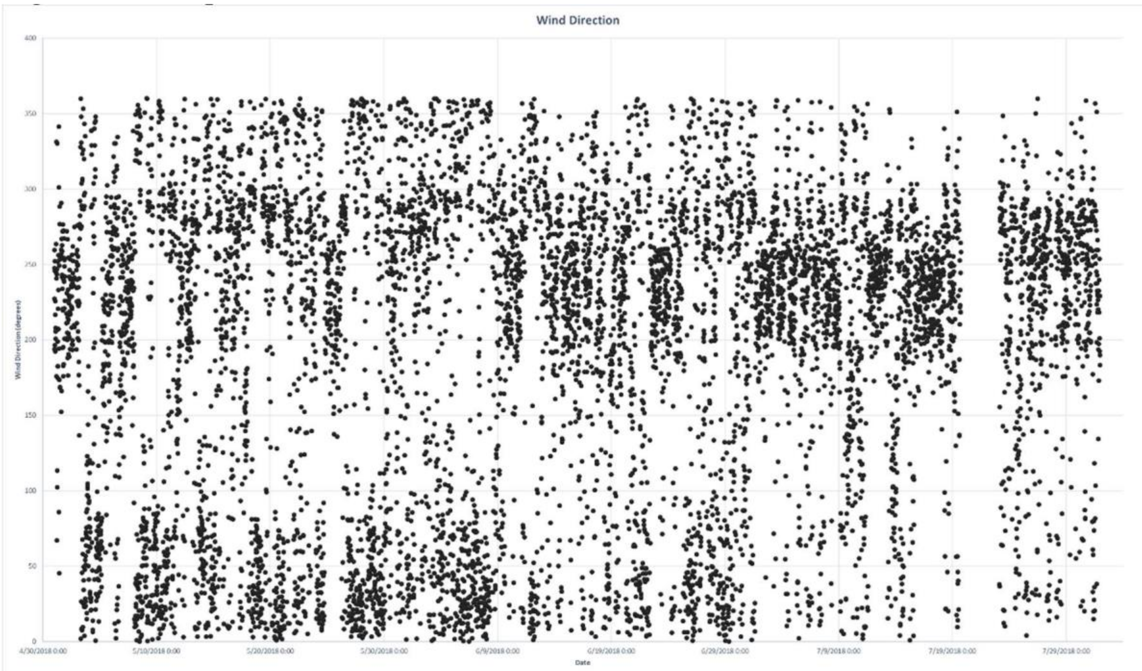

Figure 7.5 Wind direction

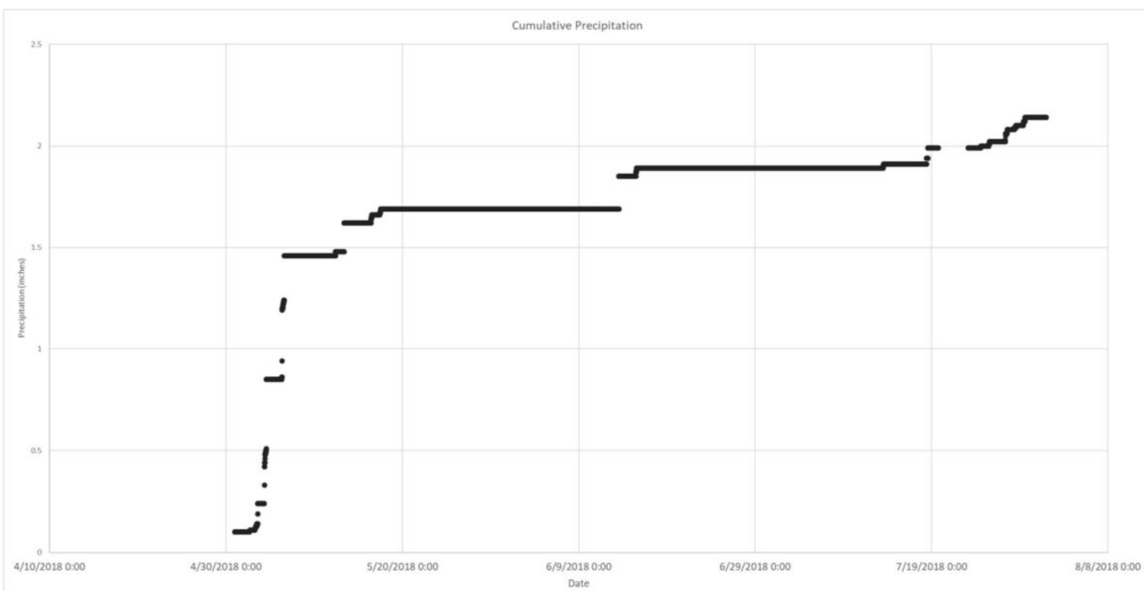

Figure 7.6 Cumulative precipitation

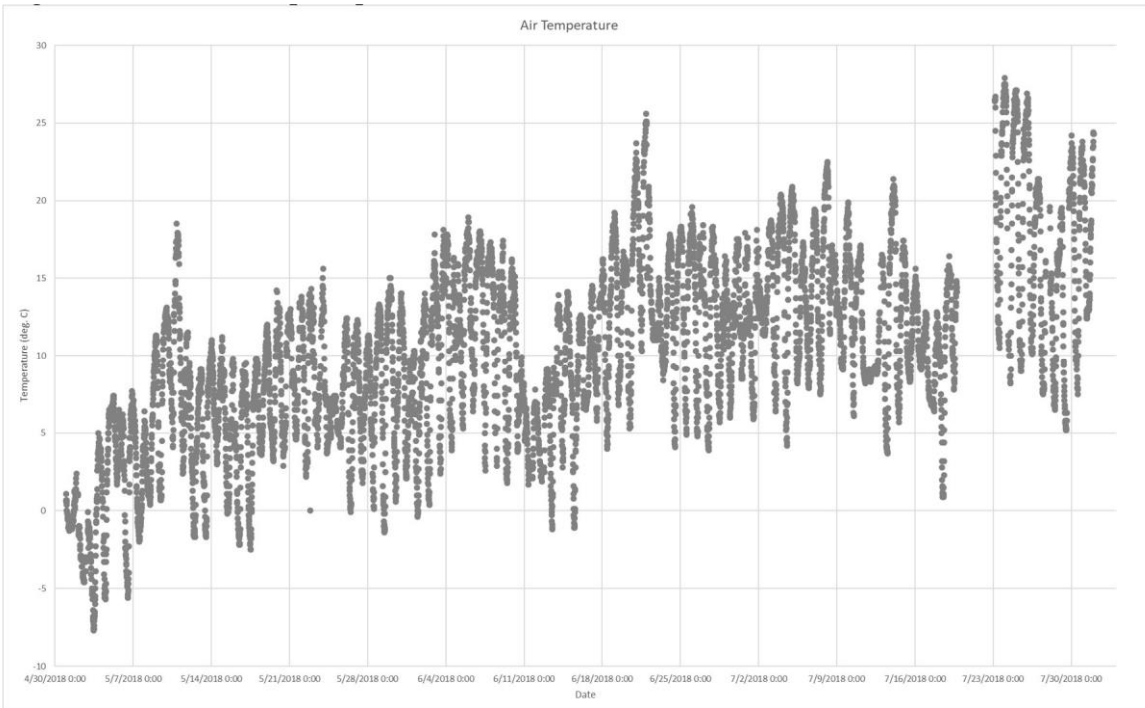

Figure 7.7 Air temperature

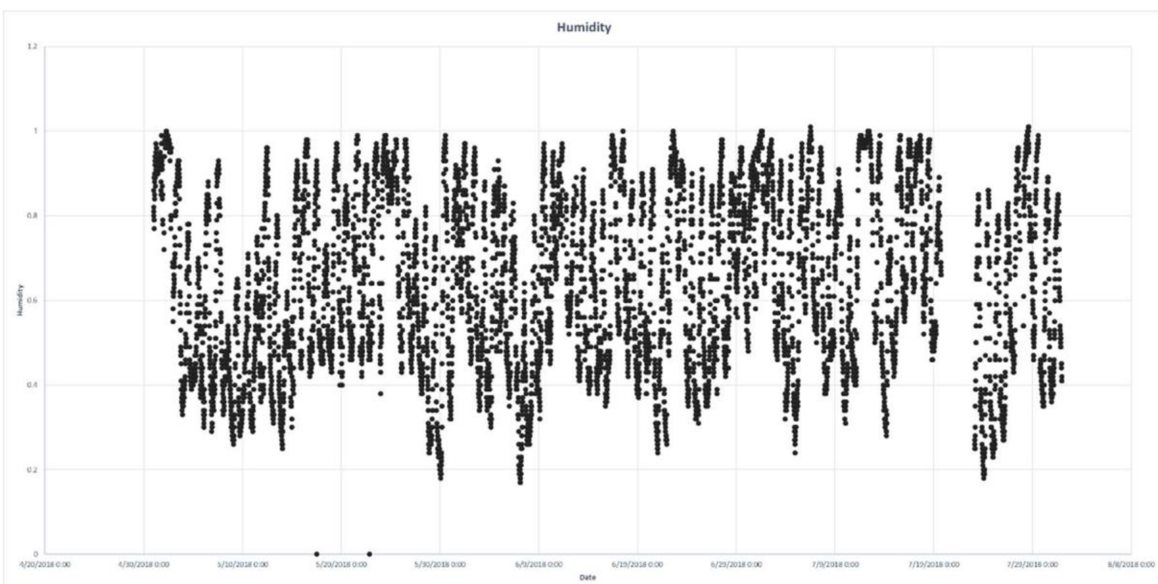

Figure 7.8 Relative humidity

8. Future

The systems will continue to be monitored for performance over the next few years. The Alaska DOT&PF plans to move the Phase II system to the roadway adjacent to the maintenance station in the summer of 2019, assuming no issues arise over the winter months. This move will make battery maintenance easy, should the solar and wind power be insufficient. The move will also minimize the cost of communications, since WiFi should be easily extended to the proposed site. Low-power radio communications will also be a viable alternative.

Now that the integration of the Phase I systems into the DOT&PF RWIS has been successfully tested, the Phase I systems will also be moved to a location as yet to be determined. It is anticipated the new locations will be on secondary roads near Fairbanks that do not have coverage at this time.

Potential users have requested the addition of a low-cost/low-power camera. While this addition has not been fully integrated, these cameras are available and should be adaptable to the system. The greatest barrier will be in cold regions where the camera must be heated to keep the lens clear. However, the size of the camera should keep the heating power demand low.

Fog prediction and detection has been a problem for DOT&PF in many areas. While MDSS predicts fog, the predictions are unreliable because of several factors. Consequently, DOT&PF is asking for low-cost fog detection. Conversations with WeatherCloud have indicated that the cost of the fog sensors is not low enough at this time for them to be widely deployed. WeatherCloud is looking into potential technologies.

9. Summary and Conclusions

This project showed that a low-cost, low-power, and reliable RWIS can be made commercially. The anticipated base cost of the system is around $10,000, which includes air temperature, ground temperature, wind speed and direction, relative humidity, snow depth, and solar insolation. This system uses line power and cellular technology. The power demand for this system averages about 10 watts at 12 volts. The system can be powered by wind or solar energy using battery buffers in most climates. In Alaska, the battery capacity may need to increase if wind power is not available during the winter months.

Phase II of this project proved that an off-grid system can be installed for less than $35,000 in Alaska. The system includes wind and solar power, mounting hardware, air temperature, wind speed and direction, relative humidity, WiFi communications, and system voltage monitoring. The system has one spare port that can be used for ground temperature, snow depth, or other sensors. The power budget for this system remains under 10 watts at 12 volts.

While in most cases cellular technologies are the most cost-effective for data transmission, cell coverage is not available along all roadways. In some cases other communication modes must be employed, including VHF/UHF radio or satellite communications. The system has been designed to adapt to these communications modes. However, at this point, modes other than cellular have not been employed.

Mounting options for the WeatherCloud RWIS are quite flexible. The site and agency mounting requirements may have a significant impact on the installation costs. Consequently, developing the system budget requires careful consideration of mounting.

Overall, the system is working well. As indicated, there is room for improvement, but it is clear that the system can be commercialized.

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