FINDINGS ON THE IN-LABORATORY EVALUATION OF ODOT INFRARED CAMERA

by

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ABSTRACT

This report documents laboratory testing of an infrared camera that the Oregon Department of Transportation intends to use for detection of winter road weather conditions. Seven controlled experiments were conducted to see how the infrared camera measured phase change between snow, ice, water and dry pavement, with respect to the actual phase change. The results of these experiments are provided, and recommendations are presented.

DISCLAIMER

ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

The Oregon Department of Transportation (ODOT) remotely measures road weather conditions, in order to help with winter maintenance operations. To improve on the accuracy of this field data, ODOT identified infrared camera technology that reportedly measures phase change of water on asphalt. Before deploying this camera (IceSight) on a widespread basis, ODOT sought to investigate how the camera recognized phase changes in a controlled laboratory environment.

Using Montana State University's cold weather chamber, researchers from the Western Transportation Institute set up seven controlled experiments. For each experiment, temperature and phase were measured every sixty seconds. These experiments, along with a summary of the results regarding phase change, are shown in the following table:

Experiment	Start Condition	Temperature Changes	IceSight Results
1	Dry asphalt	▪ Start below freezing ▪ Raise to above freezing	▪ Correctly reported dry phase
2	2 cm of snow/ice	▪ Start below freezing ▪ Raise to above freezing until entire sample has melted	▪ Correctly reported snow to water phase change
3	2 cm of snow/ice	▪ Start below freezing ▪ Raise to above freezing until melt starts to occur ▪ Lower below freezing again	▪ Correctly reported snow to water phase change ▪ Missed water to ice phase change
4	2 cm of snow/ice (w/ second asphalt puck)	▪ Start below freezing ▪ Raise to above freezing until melt starts to occur ▪ Lower below freezing again	▪ Correctly reported snow to water phase change ▪ Missed water to ice phase change
5	Thin layer of bubble-free ice	▪ Start below freezing ▪ Raise to above freezing until entire sample has melted	▪ Confused phase change from ice to snow (slush) ▪ Correctly reported snow to water phase change
6	Dry surface	▪ Lower below freezing while spraying water to make ice	▪ Correctly reported dry to water phase change ▪ Correctly reported water to ice phase change
7	Dry surface	▪ Lower below freezing while spraying water to make ice ▪ Increase temperature until melt has occurred	▪ Correctly reported dry to water phase change ▪ Correctly reported water to ice phase change with lag ▪ Correctly reported ice to water phase change

The camera had some difficulty on temperature measurements, probably due to the drastic temperature changes experienced in the cold weather chamber that would be unlikely to be replicated in a real-world deployment. The camera showed difficulty in measuring the transition from water to ice, and in interpreting slush. However, it accurately identified most phase changes despite drastic temperature changes. Based on these results, the IceSight camera would appear to merit field testing to see whether it is appropriate for broader use in Oregon.

1. INTRODUCTION

In order to effectively respond to roadway needs during winter weather, Oregon Department of Transportation (ODOT) maintenance staff need to have accurate information concerning the current road weather conditions. Good information can help maintenance staff to prioritize maintenance activities and select appropriate treatment methods.

In recent years, ODOT has invested in a network of road weather information systems (RWIS). These systems collect a variety of weather data valuable to ODOT maintenance staff, including road pavement temperature, which is often closely tied to whether ice or snow will adhere to the pavement. There has been concern, however, that the pavement temperatures as measured by the in-pavement sensors may not be sufficiently accurate.

One technology that has been applied recently to try to improve the accuracy of pavement surface condition measurement is infrared. ODOT is investigating whether or not this technology may be used to improve ODOT's existing RWIS network.

This report summarizes an initial stage in this investigation, reporting on a controlled laboratory test of an infrared camera. ODOT wanted some closed environment testing performed before employing the camera at the test site. The in-laboratory evaluation was completed at Montana State University's cold regions laboratory in the weather chamber.

Chapter 2 describes the laboratory setup and expands on specific equipment/devices that were used to setup, measure, and collect data for the experiment. The Infrared Road Ice Detection system (IRID) model B IceSight built by Innovative Dynamic Inc. is the infrared camera that ODOT chose to use for these experiments. Chapter 3 expands on how to set up and calibrate the camera, and how to use the vendor's software.

Chapter 4 explains the suggested experiments that appeared in the original scope of work and adjustments that were necessary to ensure that the experiments would work correctly. This chapter also covers the initial problems that occurred during the experiments and the methods used to fix the problems. After all the issues were tackled, seven experiments provided data that could be used to evaluate the infrared camera. The seven experiments are thoroughly discussed in Chapter 5. Chapter 6 draws some conclusions about the camera and the experiments and provides some recommendations for future users.

2. EQUIPMENT DESCRIPTION

To perform the evaluation of the infrared camera six pieces of equipment needed to be used or created: the weather chamber, Eppley Precision Spectral Pyranometer (PSP), T-Type Copper-Constantine thermocouples, two asphalt pucks, a Newport Optics neutral density filter, an Agilent data logger, and the camera tripod. This chapter will describe each of these pieces in detail.

2.1. The Weather Chamber

A recent addition to the cold regions laboratory at Montana State University is the weather chamber. The chamber is a large walk-in box where temperature, humidity, and solar radiation can be controlled. The chamber exterior and interior dimensions are 84” wide by 105” depth by 90” height and 72” wide by 84” depth by 86” height respectively. The chamber can be entered through a full-size door, allowing simple experiment set-up and break down (Figure 2-1). A computer that is located next to the chamber controls temperature, humidity, and solar radiation. The temperature of the chamber can range between –20º C and 60º C and is accurate to ±1º C. Temperature can be programmed to change throughout the experiment and proved very useful when trying to get ice to change phase.

Figure 2-1: Front Entrance Door of the Weather Chamber

The weather chamber is also equipped with a SolarConstant 4000 system. This full spectrum solar simulation system can be adjusted to provide the same solar radiation fluxes provided by the sun.

2.2. Eppley Precision Spectral Pyranometer

The Eppley Precision Spectral Pyranometer (PSP) was used to measure the solar radiation fluxes provided by the SolarConstant 4000. Measuring solar radiation fluxes helped conclude that the radiation emitted by the SolarConstant 4000 was similar to what one would expect form the sun.

2.3. T-Type Copper-Constantine Thermocouples

T-Type thermocouples were used inside the weather chamber to measure temperature. Thermocouples were placed in each asphalt sample and then used to measure the air temperature of the chamber. Figure 2-2 is a picture of the two asphalt pucks connected with the thermocouples, measuring pavement surface temperature.

2.4. Asphalt Pucks

The aggregate was made in the asphalt-testing lab at Montana State University (MSU) with the typical amounts of coarse aggregate, fine aggregate, and sands. A variation of the Marshall Method for Bituminous Mix Design was use to create the bituminous asphalt for the asphalt pucks. Two asphalt pucks were built for testing: the first puck had a diameter of 7" and the second puck had a 4" diameter (Figure 2-2). The first puck was placed directly in the line of sight of the infrared camera and was used as the primary road condition. The second puck was placed directly in the line of sight of the camera's infrared temperature sensor. The second puck was added because the diameter of the first puck was not large enough to receive both the camera's laser and the infrared temperature device.

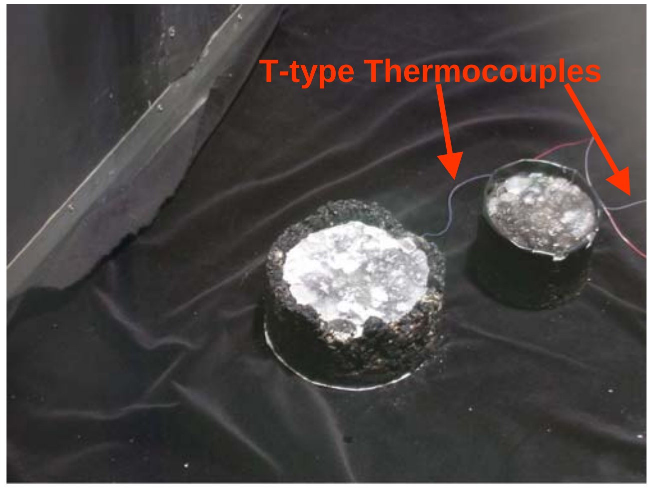


Figure 2-2: Pavement Asphalt Pucks with the Thermocouples

2.5. Newport Optics Neutral Density Filter

With the given dimensions of the weather chamber, the maximum distance between the asphalt pucks and the infrared camera was approximately seven feet. To try to simulate a scenario closer to real-world conditions, a neutral density filter was used to reduce the power of the lasers emitted from the IceSight. A neutral density filter with an optical density of 3 was placed in front of the laser receiver (Figure 2-3). An optical density of 3 will reduce the light by a thousand times, which simulates a testing distance between the camera and the asphalt pucks of approximately 30 feet.

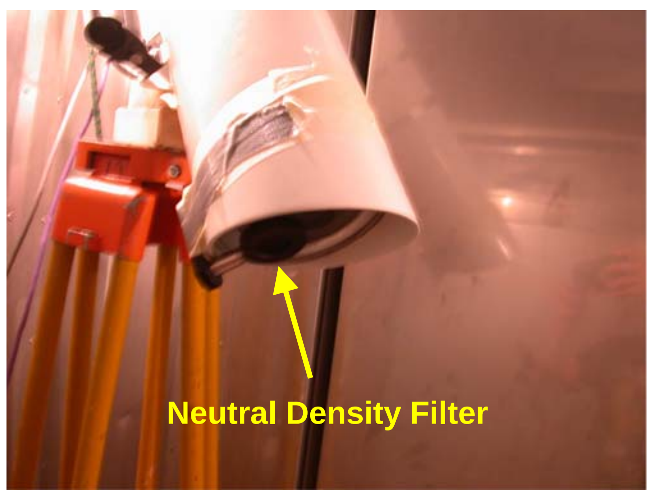


Figure 2-3: IceSight Camera with Mounted Neutral Display Filter

2.6. Agilent Data Logger

The Agilent data logger was programmed to collect solar and temperature data every minute during experiments. These data were then exported into Excel files so the data could be easily interpreted.

2.7. Camera Tripod

An old surveying tripod was used to mount the infrared camera in the weather chamber. A wood block was cut so the infrared camera could be mounted onto the wood at a 45º angle; the wood block was then mounted to the tripod. The tripod's legs were extended until the camera was in the upper corner of the weather chamber. To keep the tripod's legs from opening and to keep the camera in a stable position, a wood triangle was used to hold the legs in place. For additional stability, the camera was secured by a bungee cord to the top of the weather chamber. Figure 2-4 is a picture showing the camera-mounting device.

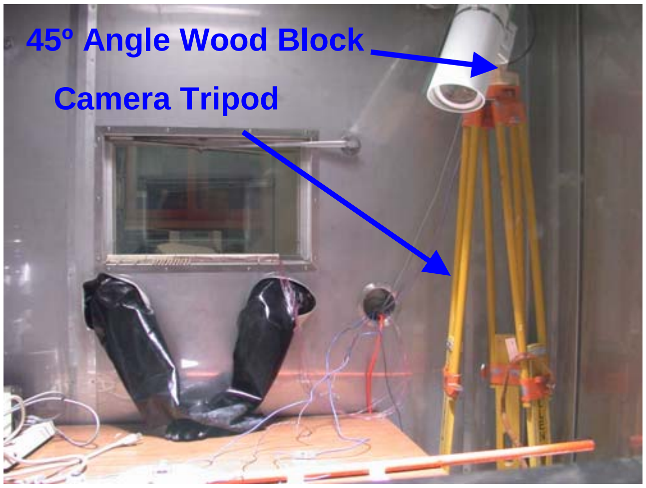


Figure 2-4: IceSight Camera and the Tripod Mount in the Weather Chamber

3. INFRARED ROAD ICE DETECTION SYSTEM

This section will explain how to run the IRID Model B IceSight (a.k.a. IceSight). Many procedures need to be followed before the IceSight is able to collect data: the software that will run the IceSight needs to be loaded on a computer, the computer needs to communicate with the IceSight, and the IceSight needs to be calibrated. This chapter provides some techniques for using the different software packages associated with IceSight. This chapter is not intended to provide step-by-step procedures on how to get the IceSight working, but does serve as a supplement to the "Users Reference Manual" provided by the vendor (1).

3.1. Installing IceSight Software

The IceSight uses two programs: ToolSet and SDK-Dispatcher. ToolSet is used to calibrate the camera; the SDK-Dispatcher is the program that is used to monitor the road conditions.

The first step to loading the provided software on the computer is to create a folder in the "C:" directory called "irid". After this folder is created, copy the contents of the software CD into this folder, following the instructions on pages 1-2 of the User Reference Manual (1). When creating the shortcuts for *gui.bat* and *dispatcher.jar* follow the five steps labeled "Desktop Shortcut Creation" on page 2 of the User Reference Manual. For step 4 "Add Application Personalization," in the Command Line {Target} for the ToolSet program type

```
C:\irid\ToolSet ToolSet 192.168.1.91
```

and for the dispatcher.jar program, type

```
C:\irid\Dispatcher.jar DispatcherB 192.168.1.91.
```

192.168.1.91 is the IP address for the IceSight with which you will be working. Along with adding the shortcuts, the *dispatcher.cfg* file needs to include the correct IceSight IP address, 192.168.1.91, and a directory path that indicates where the dispatcher files will be stored. The directory path for the *dispatcher.cfg* will be expanded on later in this chapter. After the shortcuts have been created, turn on the IceSight and see if the programs connect to the unit; if they do not, the following section will briefly address how to get the IceSight to communicate with the computer.

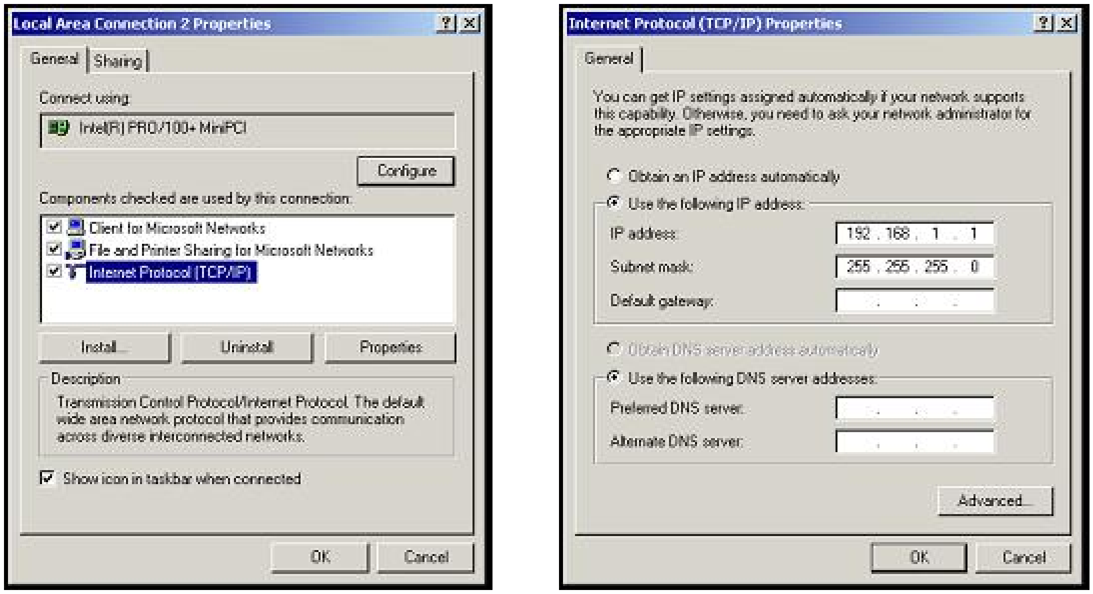
3.2. Computer Communication

If the IceSight is not communicating with the computer, this means that the IceSight and the computer are not on the same network. The network number that the IceSight communicates on is 192; therefore, go to the command prompt on the computer and type

```
route print
```

and look in the fourth column called interface; if some of the numbers are not starting with 192, then the IP address needs to be changed. To change the IP address of the computer connection, go to Start/Settings/Network and Dial-up Connections/Local Area Connection. A window screen will pop up; click on "Internet Protocol (TCP/IP)" then click on "Properties" (see Figure 3-1a). In the following window that pops up change the IP address to 192.168.1.1 and the Subnet mask to 255.255.255.0 (see Figure 3-1b). After these changes are done, the IceSight should communicate with the computer.

3.3. IceSight Calibration



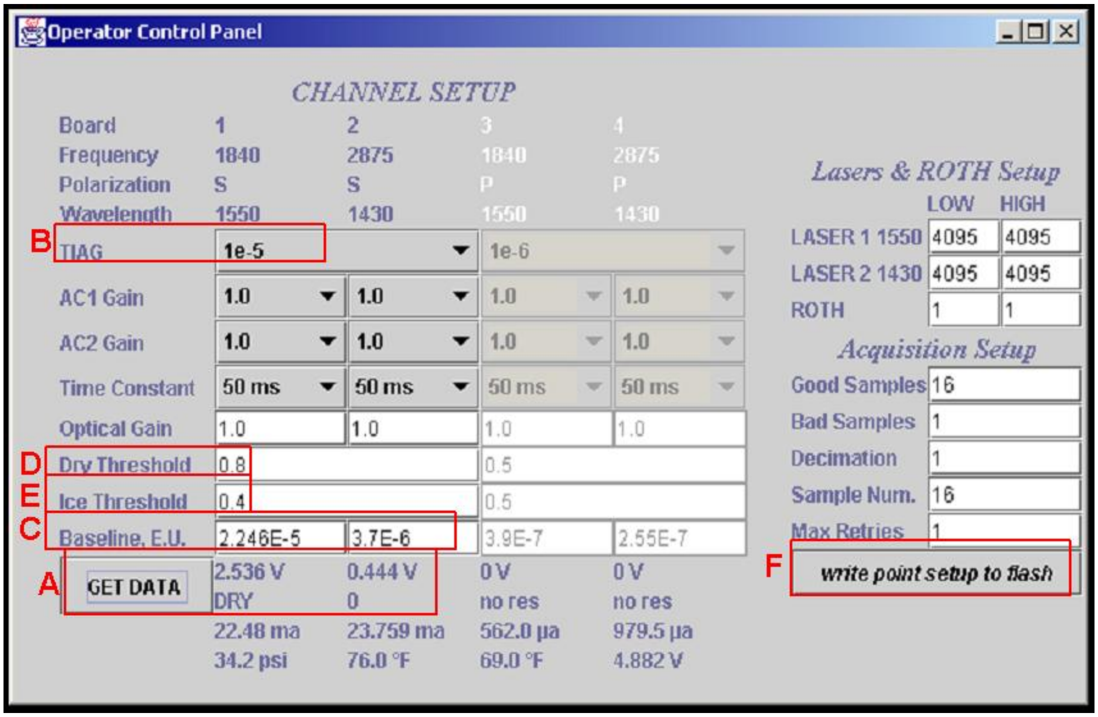
(a) (b)

Figure 3-1: Screen shots of a) Local Connection Properties Window; b) Internet Protocol Properties Window

After the IceSight is mounted in its permanent site location, the calibration process can begin. As mentioned earlier, the ToolSet program is used to perform the calibration. Double click on the ToolSet shortcut and three windows should open up. The “communications” window shows either a green or a red box, where green means the IceSight is communicating. The “road image” window allows the user to turn on the laser pointer and to take pictures. The “Operator Control Panel” window is where the calibration is done. Figure 3-2 is an image of the “Operator Control Panel” and has different areas labeled with letters to illustrate the explanation of the calibration process.

The first step is to get a reading. To do this, press “Get Data” (see Figure 3-2a). Note that calibration needs to be done with a dry surface. After “Get Data” has been completed, the condition should say “DRY” and there should be two numbers provided as output. These numbers are the voltages received back to the IceSight. If either of the voltages read 4.9999 V then the IceSight has been overloaded and the gain (TIAG) needs to be reduced. If the voltage readings are low (0.01 V), then the gain (TIAG) needs to be increased (see Figure 3-2b).

The next step is to take twelve readings recording bolt voltages, disregarding the high and the low for each column and averaging the other ten voltages to produce the baseline voltages (see Table 3-1 and Figure 3-2c). Dry and Ice Thresholds need to be set at 0.8 and 0.4, respectively (see Figure 3-2d and Figure 3-2e). Finally, after all the changes have been made, click “write point setup to flash” so all of the changes that were made in the “Operation Control Panel” will be saved (see Figure 3-2f).



A) Get Data button and voltage readings; B) Voltage gain exponent; C) Baseline voltages; D) Dry threshold constant; E) Ice threshold constant; F) Write point to setup flash button

Figure 3-2: Screen Shot of the Operator Control Panel

3.4. Dispatcher Program

The Dispatcher program is used to monitor the road condition and store the data. Double click on the shortcut for the Dispatcher; this will bring up a "Connection Properties" window (see Figure 3-3). This window provides the opportunity to either connect to the unit or give a history playback from a previous test. The "Connection Properties" window has a command line for the "Host" and "Archive Location"; these two spaces are filled with the data that was put into the *dispatcher.cfg* file. The "Host" is the IP address of the IceSight and the "Archived Location" is the directory path to the folder where the data is to be stored or to retrieve data from a previous test. To make sure not to overwrite important stored data, use a general folder for the *dispatcher.cfg* and manually enter the folder when using the "Connection Properties" window.

Table 3-1: Calibration Voltage Readings for Dry Surface

Reading #	Voltages for Board 1	Voltages for Board 2
1	2.217E-05	3.670E-06
2	2.217E-05	3.720E-06
3	2.227E-05	3.630E-06
4	2.230E-05	3.680E-06
5	2.226E-05	3.670E-06
6	2.230E-05	3.700E-06
7	2.234E-05	3.710E-06
8	2.320E-05	3.680E-06
9	2.210E-05	3.710E-06
10	2.236E-05	3.710E-06
11	2.327E-05	3.710E-06
12	2.339E-05	3.750E-06
Average Total	2.246E-05	3.70E-06

The “IRID Dispatcher GUI: R02D03” window pops up when connecting to the unit. This window provides a video image of the road condition, air temperature, pavement temperature, time the sample was acquired, channel voltages, and the road condition (see Figure 3-4). Samples are taken whenever the IceSight is ready to take another one; this is non-adjustable and occurs approximately every minute. The dispatcher is set up to take 25 samples and then overwrite the earliest sample. Clicking the “Archive Without Bound” box will allow the dispatcher to save all the data collected.

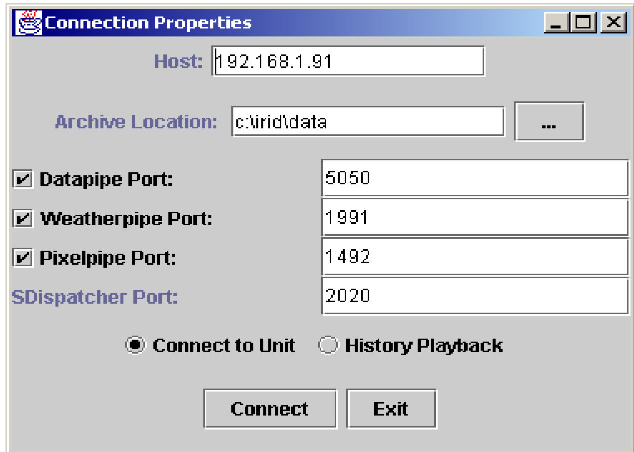


Figure 3-3: Connection Properties Window for the Dispatcher Software

Whenever the IceSight is turned off the internal clock in the camera is reset. Therefore, if the time of sample is of interest, this needs to be programmed into the IceSight. This can be done by telneting into the camera and changing the date. To perform this action, go to Start/Run and at the command line type

```
telnet 192.168.1.91
```

and click OK. This will bring up a DOS command prompt. The command prompt will ask for a user login and password, which are

```
root
```

and

```
i0r0i0d1
```

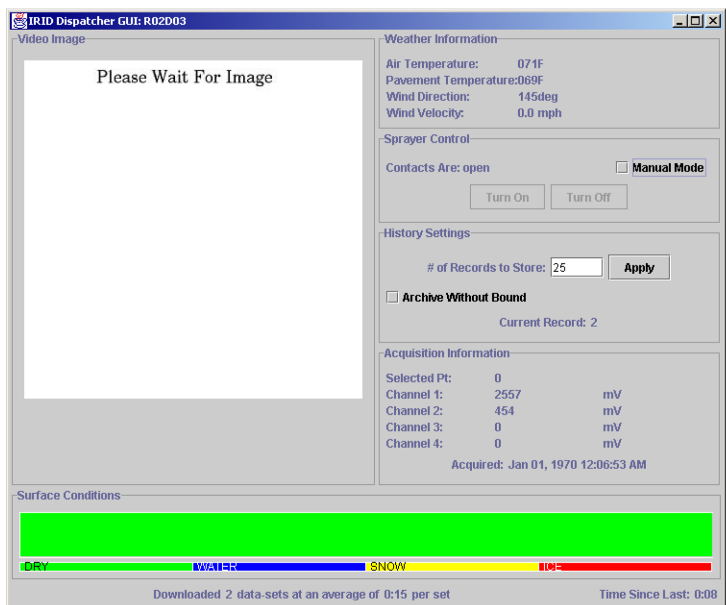


Figure 3-4: Dispatcher Software Monitor Window

respectively. To change the date in the IceSight, the command needed is

```
date –s “Month Day Hr:Min Year”
```

For example, to set the time and date for May 28, 2003 at 1:14 pm would be:

```
date –s “May 28 13:14 2003”.
```

Close the telnet session by typing

```
exit
```

4. INITIAL EXPERIMENTS

Seven different experiments were outlined in the scope of work; these are listed in **Error! Reference source not found.**. These experiments were designed to monitor different types of phase change with different surface conditions. Each of these experiments was performed once and the data was analyzed.

After analyzing the data, it was noted that visual pavement conditions were not matching what the IceSight was indicating – the IceSight was indicating snow for every phase except for the dry phase. The vendor was contacted. Upon reviewing the output files, the vendor concluded that one of the lasers may not have been fully hitting the asphalt sample. The vendor recommended spraying water on the dry asphalt surface and moving the sample around until the IceSight identified the road condition as wet, and then both of the lasers would be centered on the asphalt surface.

With the newly adjusted asphalt sample another two tests were run. These tests could distinguish between dry and water but could not distinguish between water and ice. With the neutral density filter being the exact same size as the laser receiver, there was a concern that the mount holding the neutral density filter could have been blocking returning light. Because of this problem with the mount, the neutral density filter was removed. After the filter was removed, the camera was recalibrated and the IceSight was predicting all four phases.

Table 4-1: Outline of Initial Experiments

Experiment	Start Condition	Temperature Changes
1	Dry asphalt	▪ Start below freezing ▪ Raise to above freezing
2	3 cm of snow	▪ Start below freezing ▪ Raise to above freezing until entire sample has melted
3	3 cm of snow	▪ Start below freezing ▪ Raise to above freezing until melt starts to occur ▪ Lower below freezing again
4	1 cm of snow/ice	▪ Start below freezing ▪ Raise to above freezing until entire sample has melted
5	1 cm of snow/ice	▪ Start below freezing ▪ Raise to above freezing until melt starts to occur ▪ Lower below freezing again
6	Thin layer of bubble-free ice	▪ Start below freezing ▪ Raise to above freezing until entire sample has melted
7	Thin layer of bubble-free ice	▪ Start below freezing ▪ Raise to above freezing until melt starts to occur ▪ Lower below freezing again

5. REVISED EXPERIMENTS

While getting more familiar with the IceSight, it seemed that some of the suggested experiments in the scope of work would not provide additional useful information but would only duplicate the results of a similar experiment. Experiments 2 & 4 and 3 & 5 were combined because the IceSight predicts both of those surface conditions (snow/ice and compacted snow) as snow. In addition, an experiment that was requested but not in the scope of work was also added to the experiment list. This added experiment involved spraying water onto a dry piece of asphalt and then reducing the temperature until the sample froze. The revised list of experiments is provided in Table 5-1.

The next seven sections of this chapter will expand on each of the experiments mentioned above. Two plots are provided with each experiment. The first plot is a temperature versus time plot showing chamber temperature, pavement temperature, pavement temperature 2, IceSight air temperature, and IceSight pavement temperature. The pavement temperature reading comes from the thermocouple mounted to the asphalt puck under the laser. The pavement temperature 2 reading comes from the thermocouple mounted to the asphalt puck in the line of sight with the infrared temperature sensor on the IceSight.

The second plot is a bar chart of the road condition versus time. The first bar for each time step is the IceSight road condition prediction and the second bar is the visual road condition. Road

Table 5-1: Outline of Revised Experiments

Experiment	Start Condition	Temperature Changes
1 – Dry asphalt	Dry asphalt	▪ Start below freezing ▪ Raise to above freezing
2 – Snow/ice, melt	2 cm of snow/ice	▪ Start below freezing ▪ Raise to above freezing until entire sample has melted
3 – Snow/ice, melt and freeze	2 cm of snow/ice	▪ Start below freezing ▪ Raise to above freezing until melt starts to occur ▪ Lower below freezing again
4 – Snow/ice, melt and freeze with second puck	2 cm of snow/ice (w/ second asphalt puck)	▪ Start below freezing ▪ Raise to above freezing until melt starts to occur ▪ Lower below freezing again
5 – Bubble-free ice, melt	Thin layer of bubble-free ice	▪ Start below freezing ▪ Raise to above freezing until entire sample has melted
6 – Spray, freeze	Dry surface	▪ Lower below freezing while spraying water to make ice
7 – Spray, freeze and melt	Dry surface	▪ Lower below freezing while spraying water to make ice ▪ Increase temperature until melt has occurred

condition on the bar chart is displayed by the coding shown in Table 5-2. A phase change is not instantaneous; therefore, boxes have been added to both of the plots to represent the time during the phase change. These boxes have been colored to represent the different changes; the meaning of these colors is shown in Table 5-2.

Table 5-2: Legend for Pavement Condition Figures

Number	Pavement Condition
1	snow
2	ice
3	water
4	dry

Color	Phase Change
red	water to ice
blue	ice to water snow to water dry to water
yellow	ice to snow
green	water to dry

5.1. Experiment 1 – Dry Asphalt

Experiment 1 was performed to test the IceSight's ability to detect the dry phase at temperatures above and below freezing. During this experiment, the IceSight seemed to overpredict the air temperature and the pavement temperature. The IceSight's air temperature at the beginning is higher then the actual air temperature (see Figure 5-1). A reason for this could be that the temperature of the weather chamber was very warm (25º C) before the experiment began and then temperatures were reduced drastically to –5º C. During the experiment, the IceSight air temperature reading increased more than the actual weather chamber temperature. This could be because the IceSight air temperature sensor was closer to the solar radiation source then the weather chamber's thermocouple. There is no pavement temperature 2 reading in this experiment because the second asphalt puck was not set up yet. This is also the reason that the IceSight's pavement temperature is higher then the actual pavement temperature.

The IceSight predicted the correct phase for the entire test – dry (see Figure 5-2).

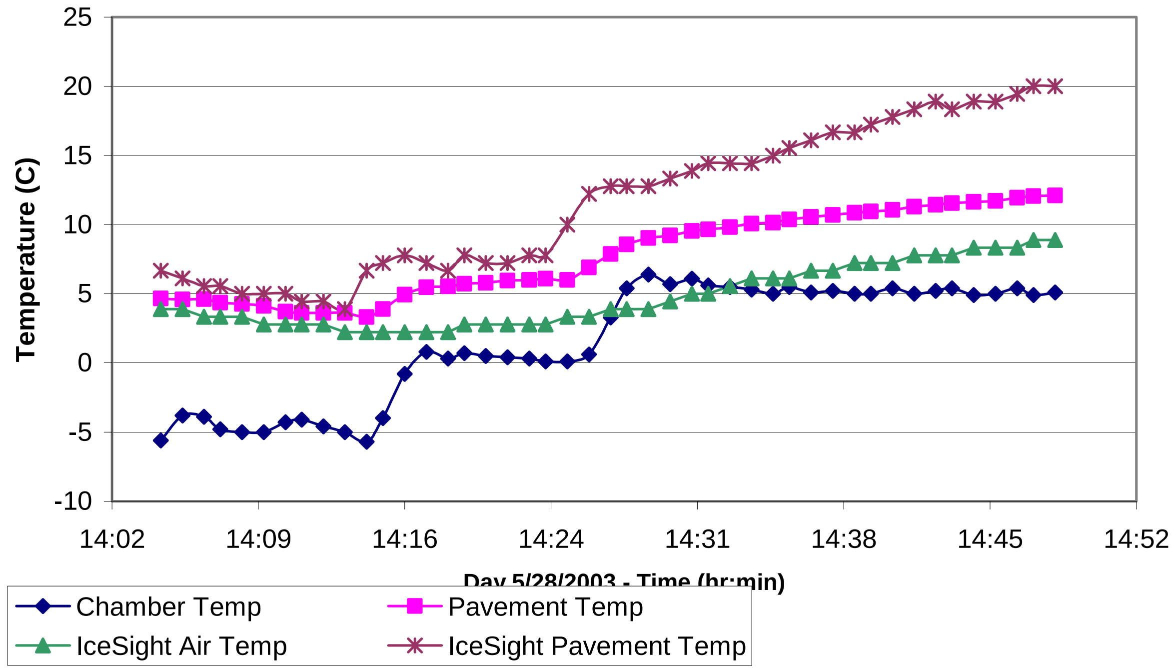


Figure 5-1: Experiment 1, Temperature vs. Time

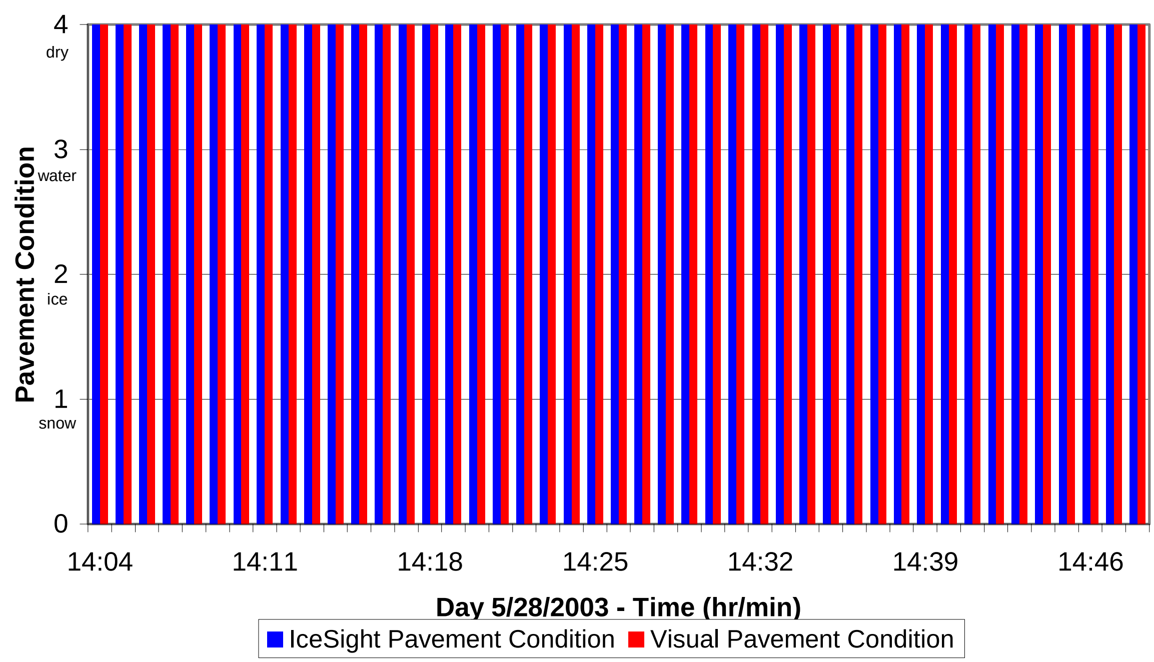


Figure 5-2: Experiment 1, Asphalt Pavement Surface Conditions

5.2. Experiment 2 – Snow/Ice, Melt

Experiment 2 consisted of 2 cm of hard snow. The experiment began at temperatures below freezing – -5º C – and the temperature was increased to 30º C to try to achieve two phase changes: snow to water and water to dry (see Figure 5-3). During this experiment the pavement temperature 2 thermocouple was having difficulties; therefore this data is not shown in Figure 5-3. The air temperature of the IceSight started a littler higher then the actual air temperature and increased more slowly then the actual temperature, but ended at the same temperature. During all the experiments, it seems that the IceSight's air temperature cannot react to the fast temperature changes that the weather chamber can perform. This should not be an issue in the field because drastic temperature changes, such as –5º C to 30º C in minutes, do not occur regularly. The IceSight pavement temperature is higher for the same reason as in Experiment 1 (no second asphalt puck was in place). In Figure 5-3, the blue box indicates that the phase change from snow to water occurs as the pavement sample starts getting warmer then 0º C, the melting or freezing temperature of water. This same phase change is predicted correctly by the IceSight (see the blue box in Figure 5-4). It was not possible to get the sample to the dry phase because of the high humidity in the weather chamber; therefore the pavement surface was always wet. The two bars indicating a dry phase shown in Figure 5-4 are caused because the IceSight was reading the phase of the sample-tester's clothing while he was in the chamber checking the pavement condition.

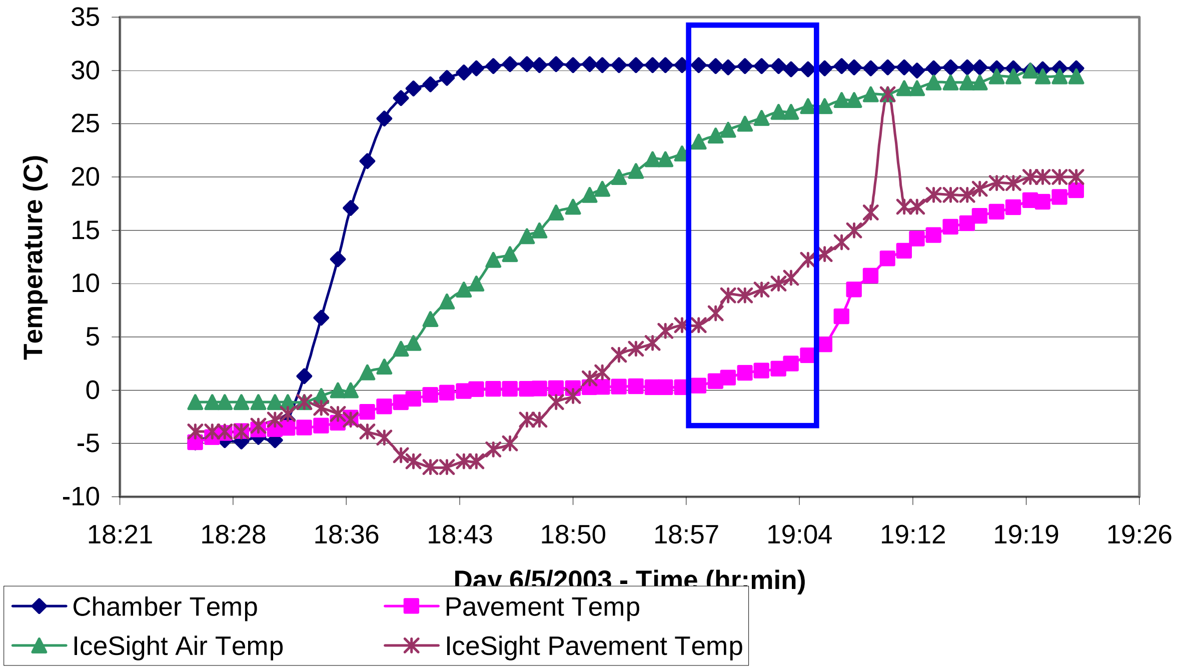


Figure 5-3: Experiment 2, Temperature vs. Time

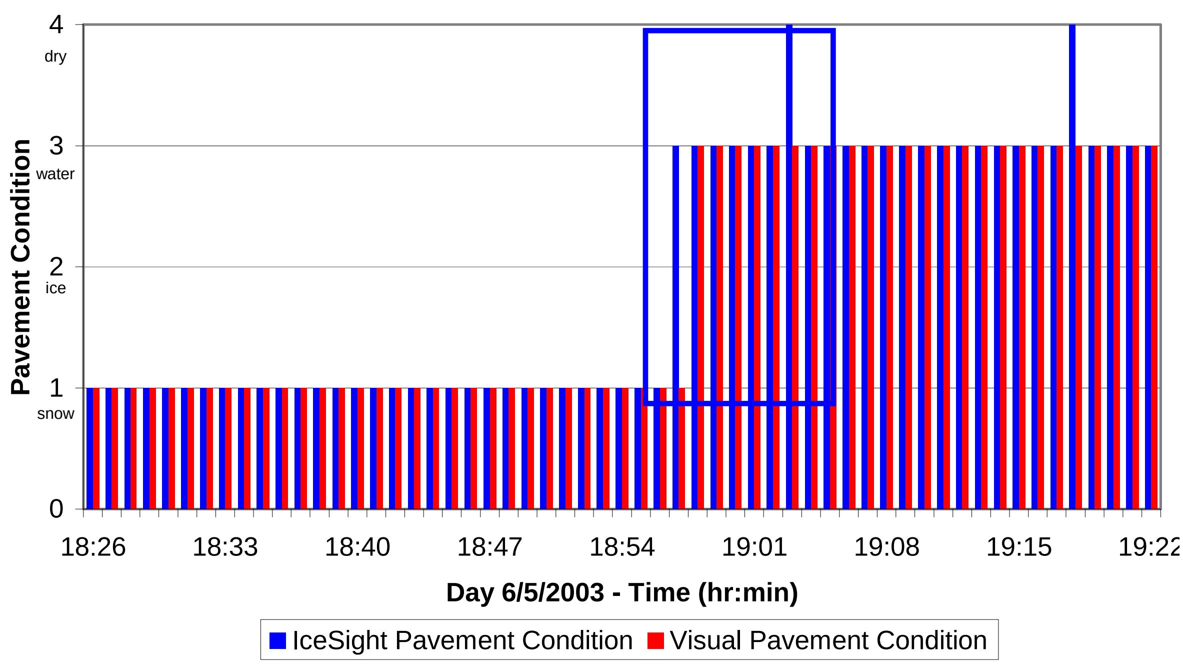


Figure 5-4: Experiment 2, Asphalt Pavement Surface Conditions

5.3. Experiment 3 – Snow/Ice, Melt and Freeze

The third experiment consisted again of 2 cm of hard snow. This experiment was created to test the IceSight's ability to predict a phase change from snow to water and then from water to ice. In this experiment, the IceSight's air temperature followed the same trends as the weather chamber but could not keep up with the quick temperature changes (see Figure 5-5). The IceSight's pavement temperature predicts temperatures higher then the pavement thermocouples during the phase change periods (see Figure 5-5). An explanation for this could be that the IceSight is reading the temperature from the top surface of the snow and slush, not the pavement temperature; and the thermocouples are reading the temperature from the bottom. A temperature of 0º C is expected during a phase change, and because the actual pavement is insulated from the snow, slush, and ice the temperature should be 0º C.

Phase change from snow to water is shown Figure 5-5 and Figure 5-6 with a blue box and the phase change from water to ice is shown with a red box. In this experiment the IceSight did not predict the phase change from water back to ice (see Figure 5-6). This may have resulted from the pavement sample not being exactly aligned with the IceSight's lasers.

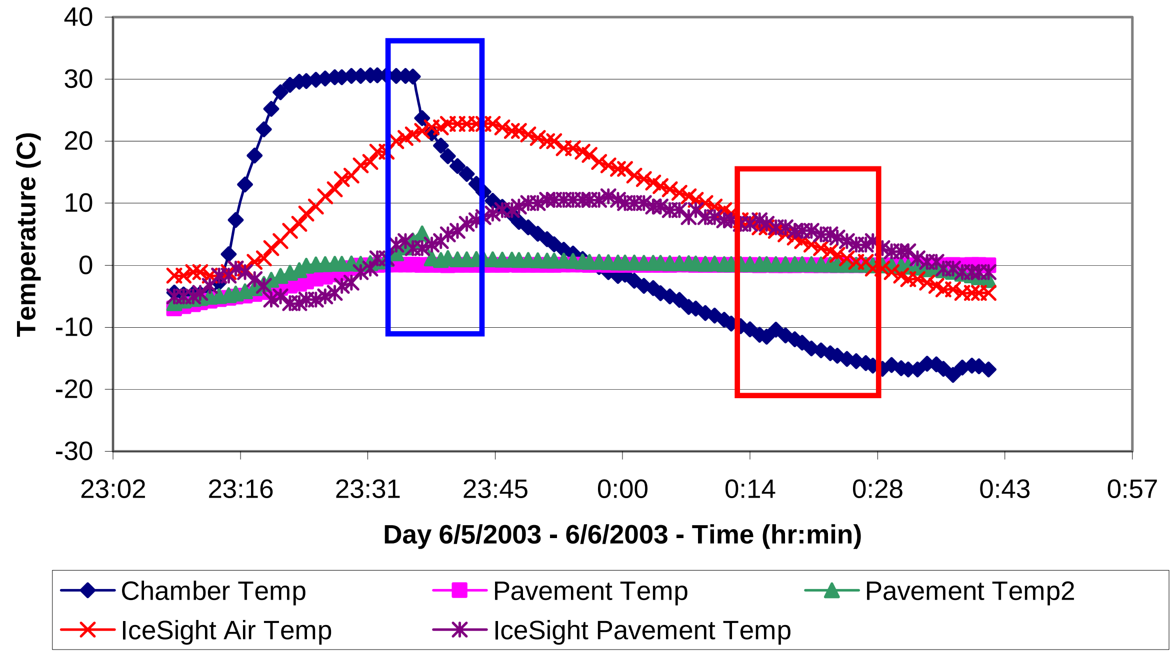


Figure 5-5: Experiment 3, Temperature vs. Time

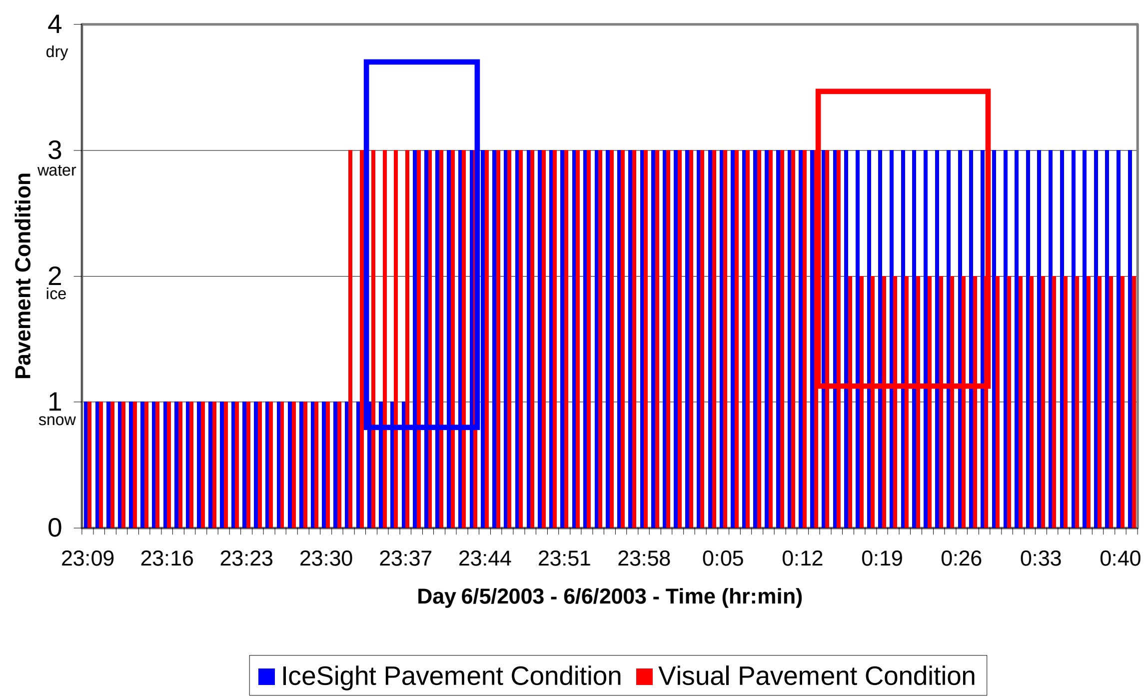


Figure 5-6: Experiment 3, Asphalt Pavement Surface Conditions

5.4. Experiment 4 – Snow/Ice, Melt and Freeze (with second puck)

Experiment 4 was the last experiment performed with 2 cm of hard snow. This experiment is the same experiment as Experiment 3 but adding the adjusted pavement sample to try to get the ice phase recognized. The same issues related to the IceSight's pavement and air temperatures occurred during this experiment (see Figure 5-7). Although the pavement sample was adjusted, the ice phase was never recognized as intended (see Figure 5-8). This may have resulted from the size of the pavement sample, although in other experiments 5, 6, and 7 the ice phase is shown.

Figure 5-9 and Figure 5-10 are screen shots of the Dispatcher during the experiment showing the phases of snow and water respectively. Notice in both of the Dispatcher screen shots that the two asphalt pucks are highlighted with the color associated with the phase.

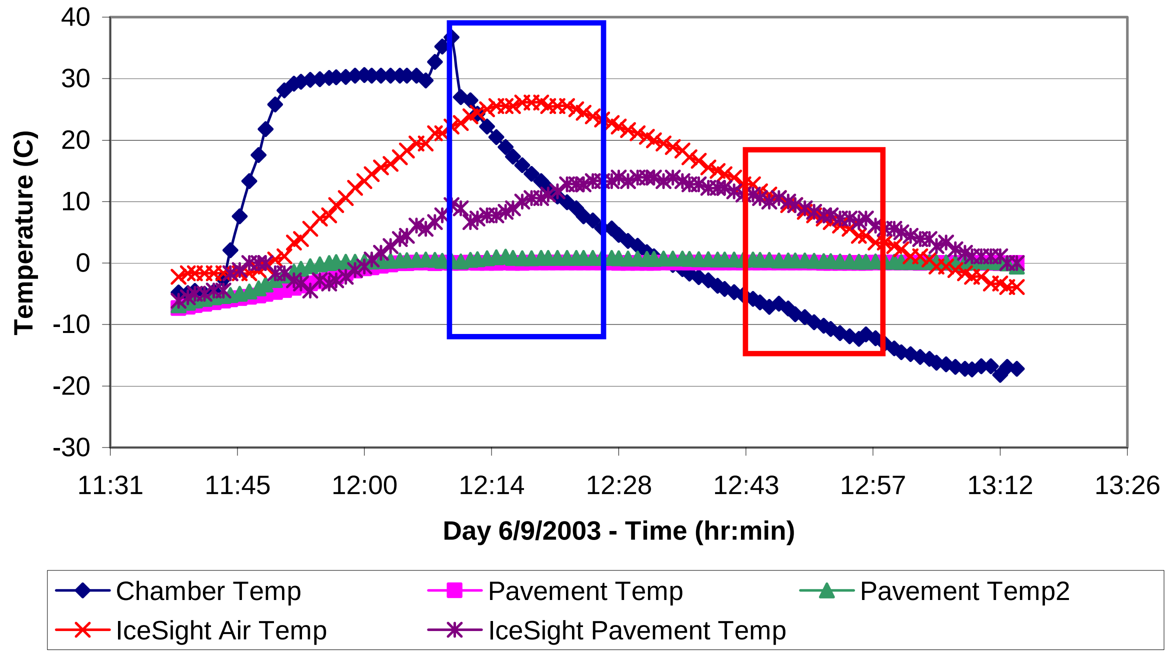


Figure 5-7: Experiment 4, Temperature vs. Time

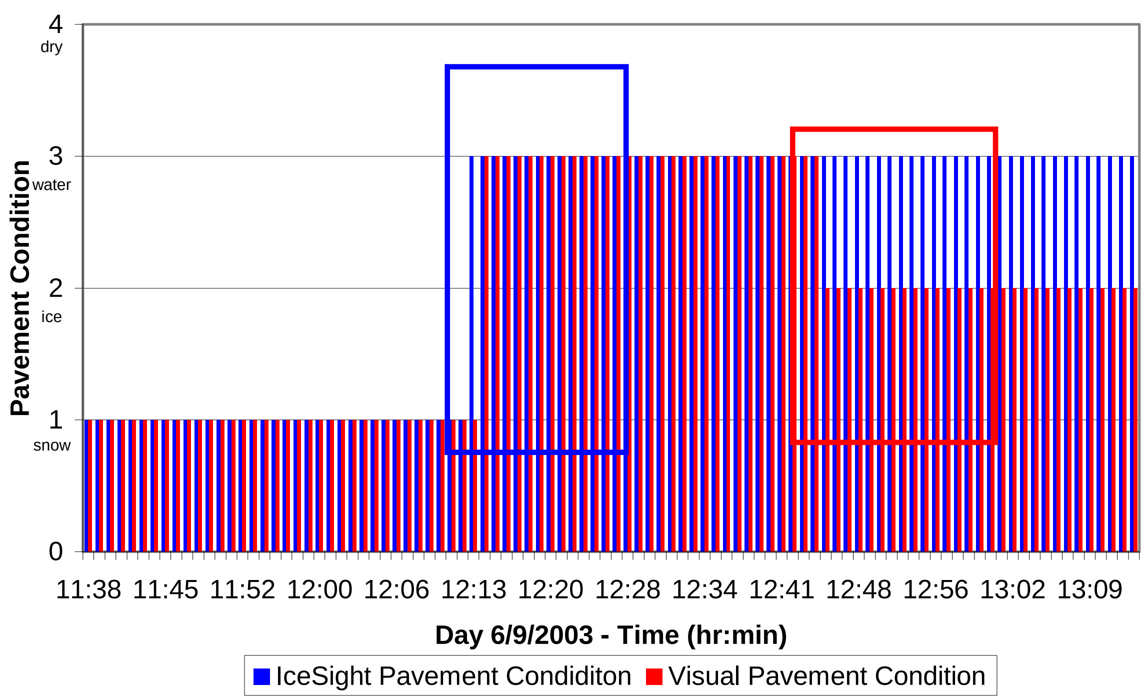


Figure 5-8: Experiment 4, Asphalt Pavement Surface Conditions

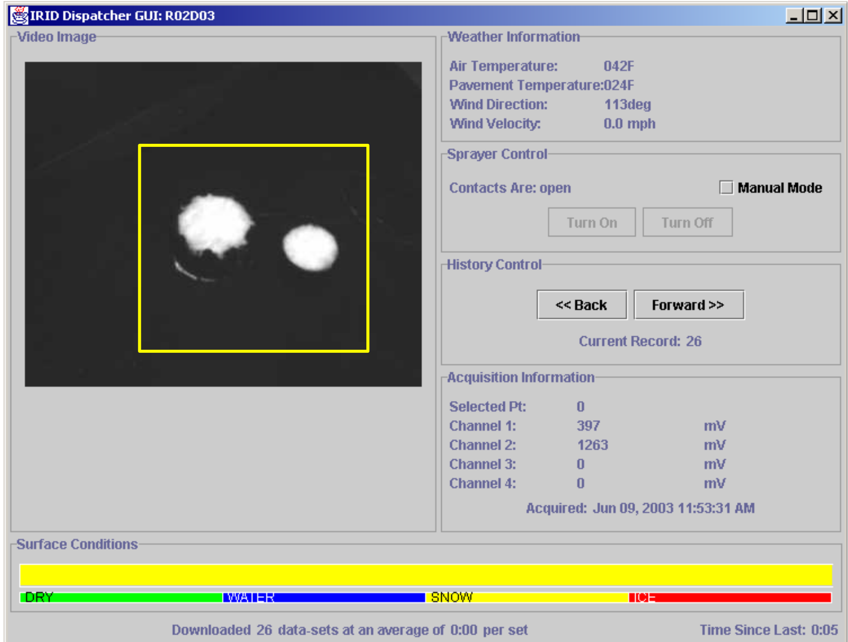


Figure 5-9: Screen Shot from Dispatcher Software Showing a Snow Surface Condition

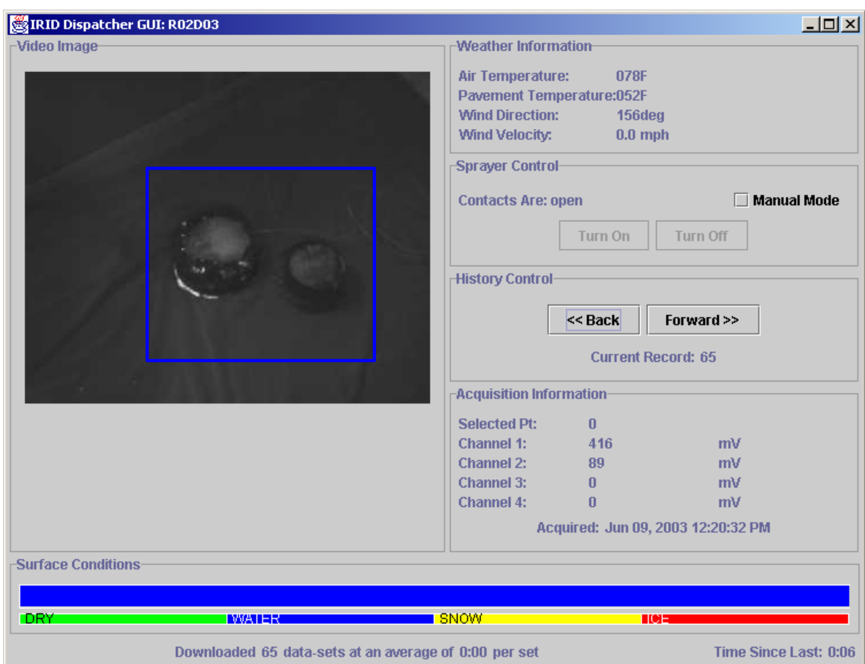


Figure 5-10: Screen Shot from Dispatcher Software Showing a Water Surface Condition

5.5. Experiment 5 – Bubble-free Ice, Melt

Experiment 5 consisted of a layer of bubble-free ice. The temperature began below freezing and increased until the ice was completely melted. This experiment shows the IceSight's ability to predict the ice phase along with accurate phase changes. The IceSight's pavement temperature did a good job at predicting the pavement temperature 2, the sample aligned with the IceSight's IR temperature sensor (see Figure 5-11). This experiment had an unusual result: as the ice began to melt, it appeared very slushy, and therefore the IceSight predicted the phase to be snow (see the yellow box in Figure 5-11 and Figure 5-12).

As the slush began to melt into water, the IceSight predicted the phase change accurately (see Figure 5-12). Again, the dry bar at 11:45 is because of sample-tester interference. After all the water had run off the asphalt surface, the sample was dried with a paper towel. The dry bar at 12:07, shown in Figure 5-12, was not sample-tester interference but an actual reading of dry. However, with the high humidity of the chamber the sample became moist again.

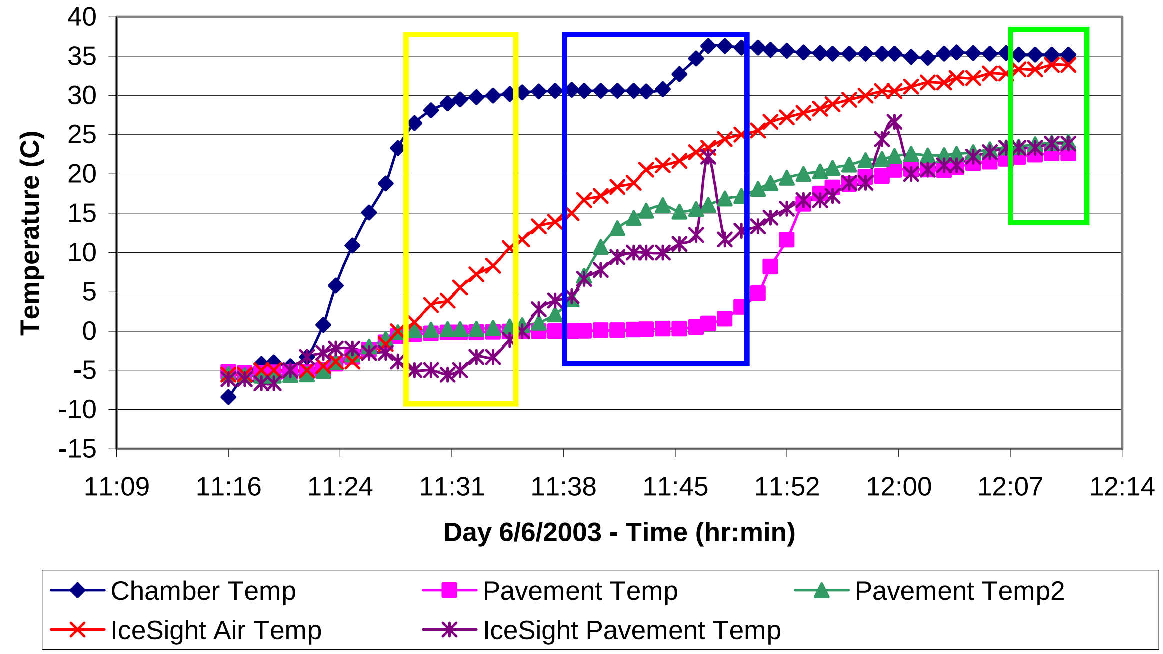


Figure 5-11: Experiment 5, Temperature vs. Time

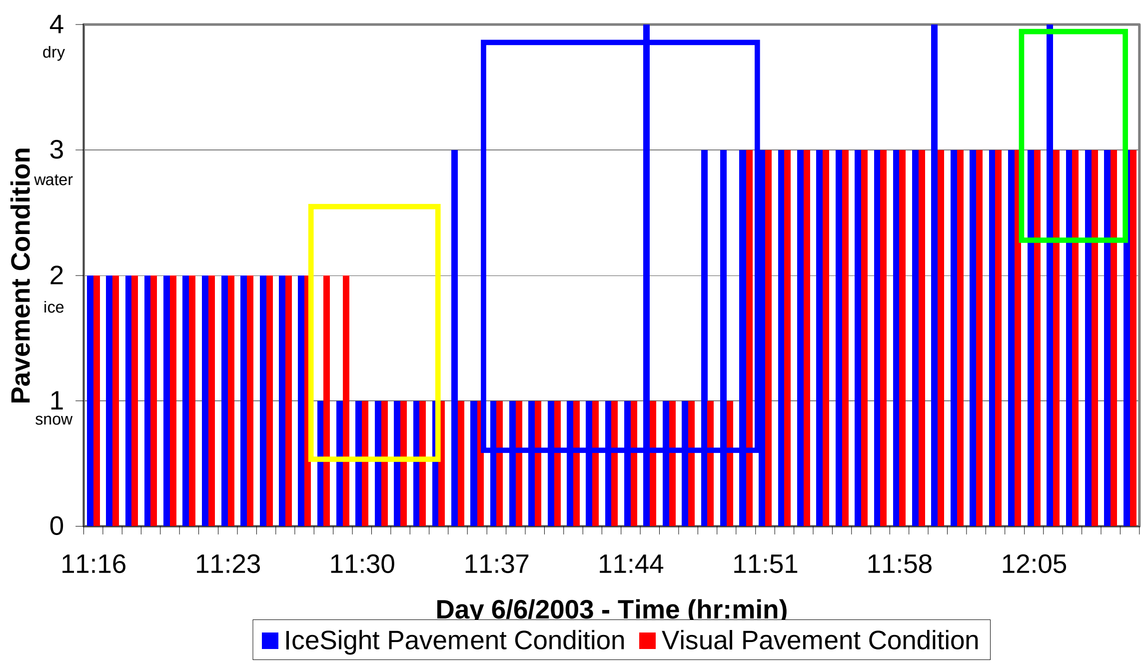


Figure 5-12: Experiment 5, Asphalt Pavement Surface Conditions

5.6. Experiment 6 – Spray, Freeze

Experiment 6 and 7 were added to show the IceSight's ability to predict the phase changing from dry to water and then to ice. This experiment was done by starting with the air temperature of the weather chamber above freezing and lowering the temperature below freezing while spraying water onto the asphalt pavement surfaces (see Figure 5-13). Experiment 6 was a short test with extreme temperature change, which is shown in Figure 5-13. The IceSight was not able to follow the air temperature change (see Figure 5-13). Both of the phase changes (dry to water, and water to ice) were predicted accurately, within one to two minutes, by the IceSight (see Figure 5-14).

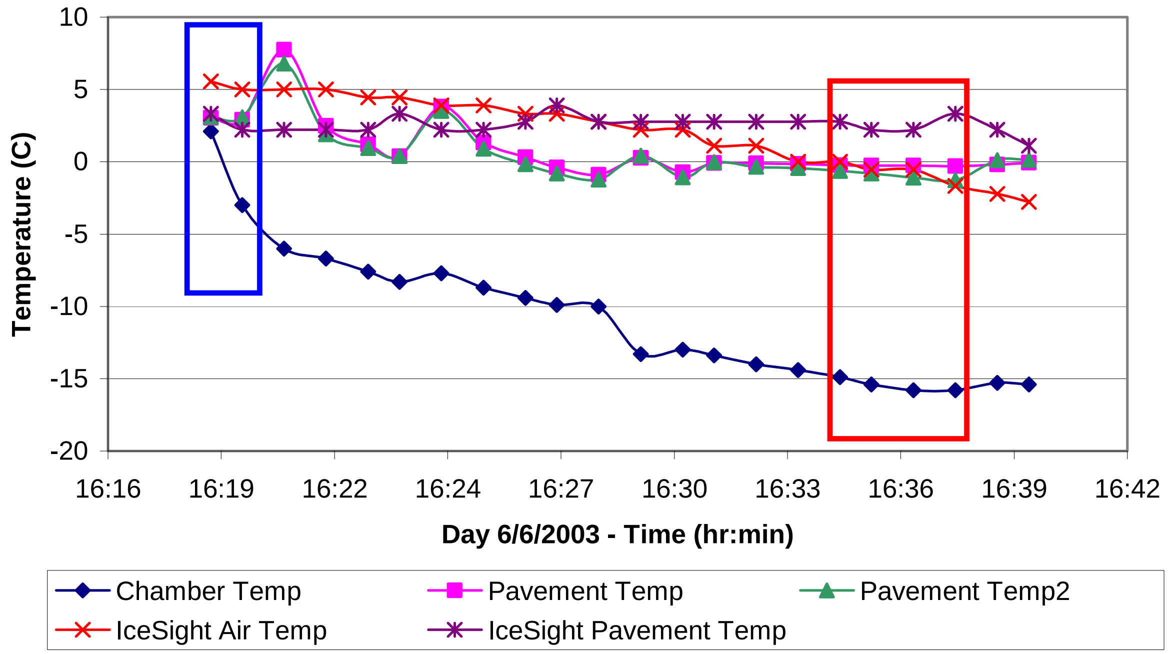


Figure 5-13: Experiment 6, Temperature vs. Time

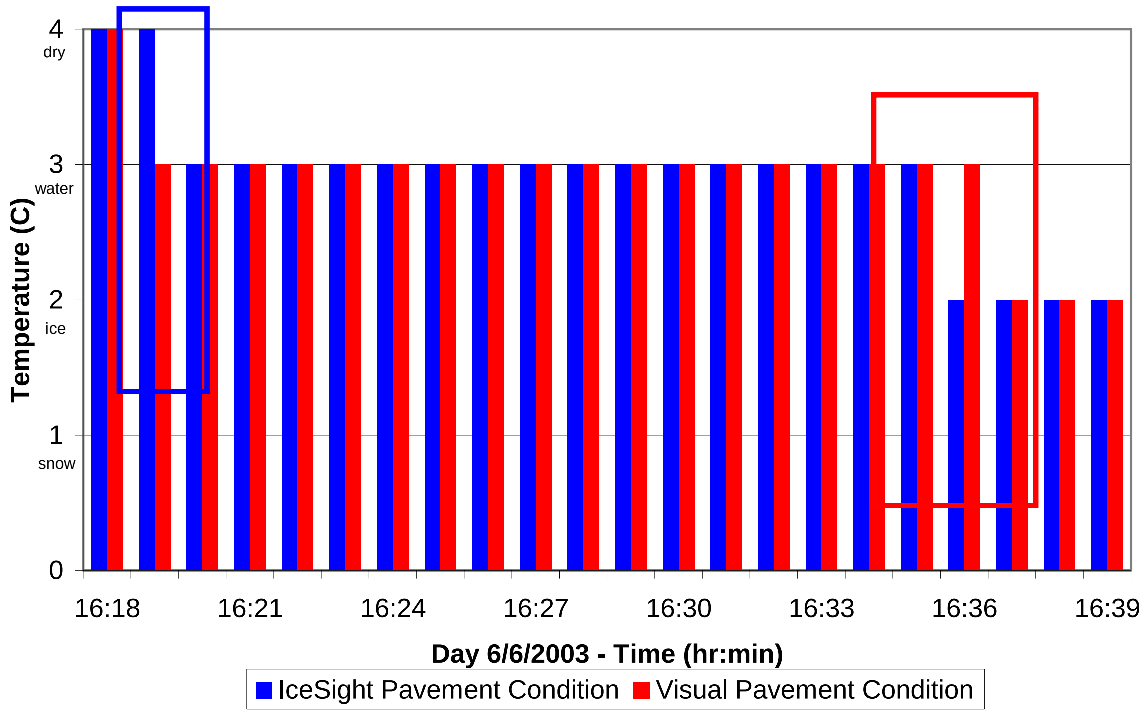


Figure 5-14: Experiment 6, Asphalt Pavement Surface Conditions

5.7. Experiment 7 – Spray, Freeze and Melt

The final experiment, 7, mimicked Experiment 6; however, after the ice surface was formed, the temperature was increased to get the ice to change phases back to water. The IceSight air temperature reading had the same problem as in the previous experiments (see Figure 5-15). The IceSight pavement temperature is accurate except for when the pavement has ice on it. This could be for the same reason as explained above: the IceSight is reading the temperature of the ice surface and the thermocouples are measuring the temperature at the pavement surface.

The phase changes are predicted accurately by the IceSight (see Figure 5-16). The blue box around the final phase change in Figure 5-16 covers a long period because the ice changed phase slowly, which left both water and ice on the surface for approximately 15 minutes. The IceSight did not predict the change until all of the ice had melted. Figure 5-17 and Figure 5-18 display screen shots from the Dispatcher of the other two phases, dry and ice respectively.

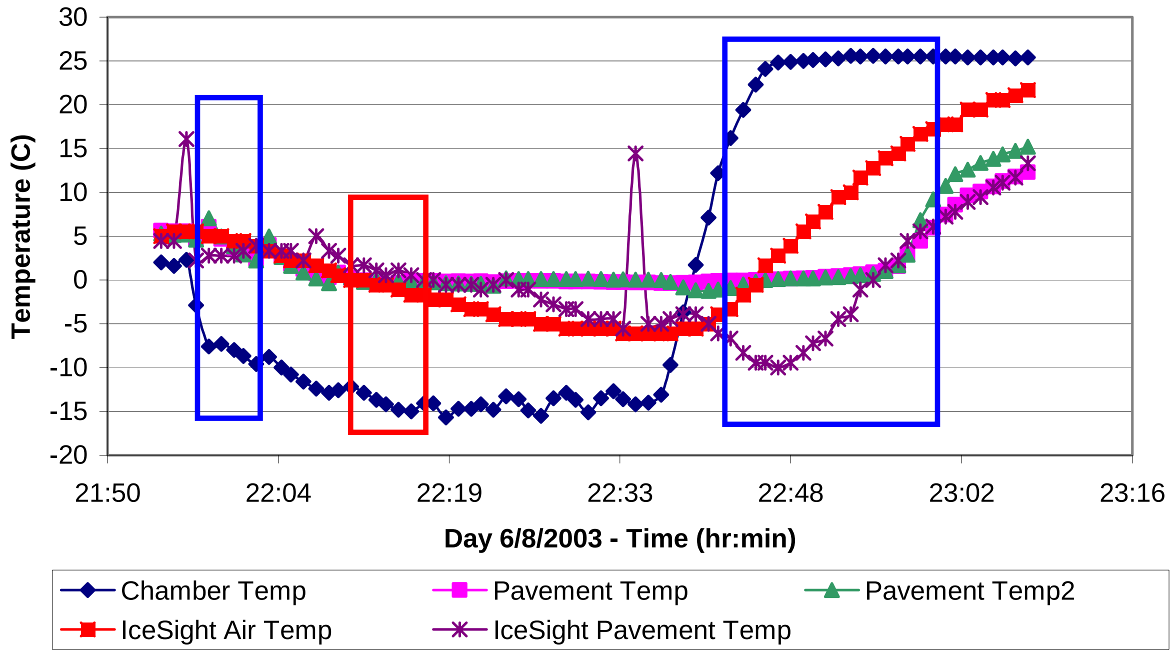


Figure 5-15: Experiment 7, Temperature vs. Time

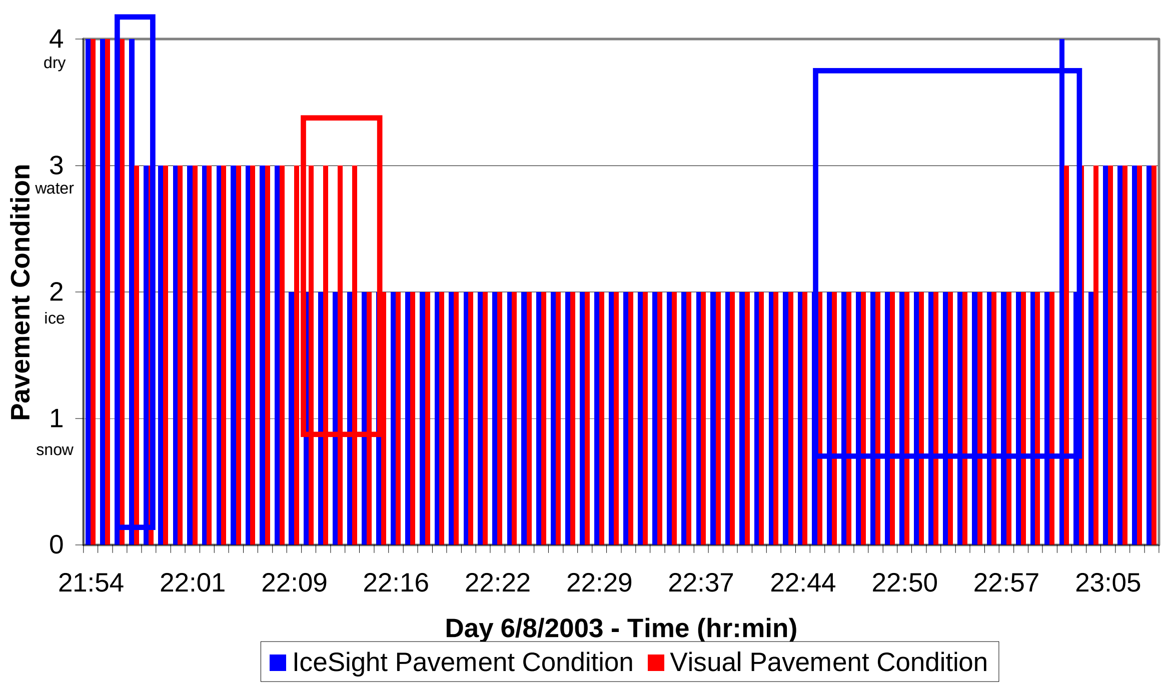


Figure 5-16: Experiment 7, Asphalt Pavement Surface Conditions

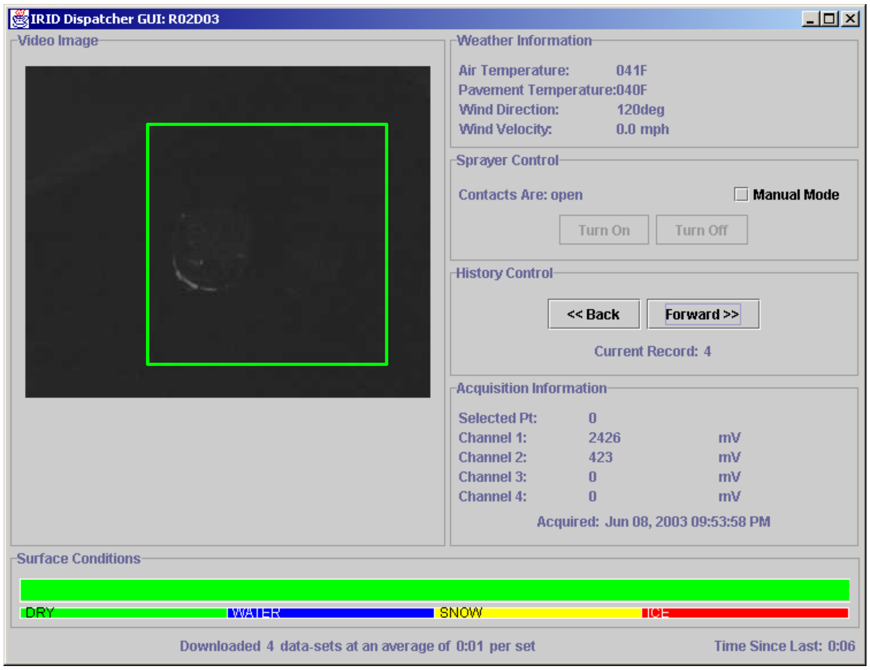


Figure 5-17: Screen Shot from Dispatcher Software Showing a Dry Surface Condition

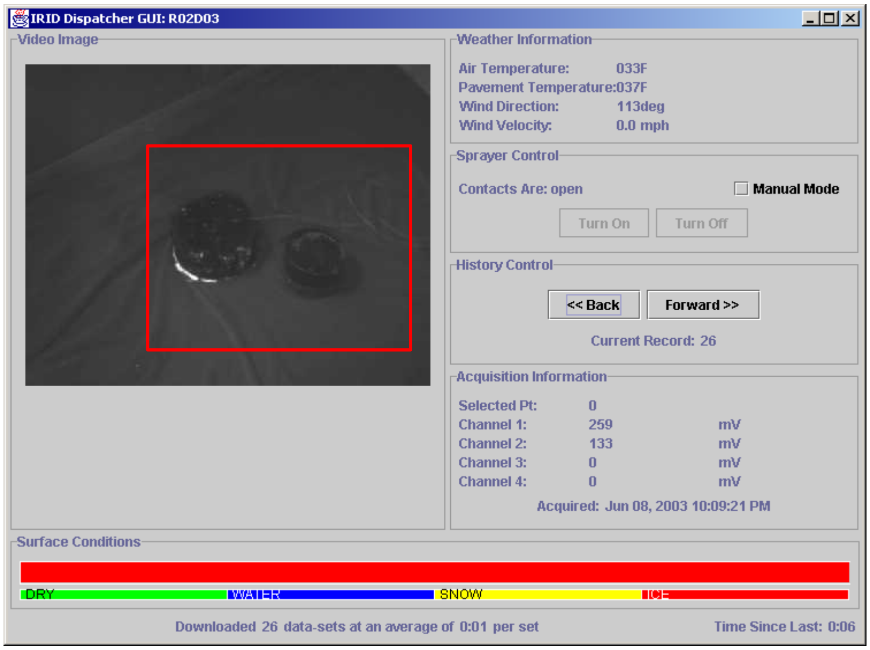


Figure 5-18: Screen Shot from Dispatcher Software Showing an Ice Surface Condition

6. SUMMARY OF RESULTS AND NEXT STEPS

6.1. Review of Initial Experiments

The initial scope for the evaluation of the IceSight camera described seven experiments that would test the IceSight's ability to predict all different types of phase changes. The initial round of experiments showed that the camera was not performing as expected. After multiple contacts with the vendor, Innovative Dynamics Inc., ideas were provided on how to better conduct this research.

- The neutral density filter was removed because it was too small to cover the entire laser receiver and was blocking some of the light reflected back into the camera. The removal of the neutral density filter should not affect the results because the voltage gain is adjusted, as a normal part of the calibration process, according to the distance the camera is away from the sample.
- The second asphalt puck was added because the infrared temperature pavement sensor is mounted to the side of the IceSight and was not detecting the single asphalt puck, therefore giving incorrect readings.
- The 1 cm of snow/ice and 3 cm of compacted snow were combined into one experiment because both experiments were testing the same phases and it seemed more important to add other experiments that would help better evaluate the IceSight.
- The experiments showing the change between dry and icy pavement conditions were added as a request from ODOT.

6.2. Review of Revised Experiments

Based on the changes made in the previous section, a new set of seven experiments was performed. The results of these experiments are summarized in Table 6-1. After performing the evaluation of the IceSight camera, there is mixed feedback on the product. The IceSight did not track the air temperature very well. This could have resulted from the rapid and drastic temperature changes occurring in the weather chamber, but one would still expect the camera to measure the air temperature more accurately. During Experiments 3 and 4, when 2 cm of hard snow was heated until melted and then cooled until frozen, the IceSight did not predict the phase change from liquid water to ice in either experiment. This could prove to be a problem in cases where there is melting slush during the daytime followed by cold temperatures at night, forming ice surfaces. Another area of concern for the camera is distinguishing the correct phase of slush. If the slush is mostly water, the IceSight will predict the phase as water and this can be a problem because slush can be very slick.

Although there are some issues with the IceSight predicting temperatures, and some phases in certain situations, the IceSight overall works very well in a controlled environment. The findings from the environmental chamber are promising. The in-lab testing provides confirmation that the IceSight is able to identify all four surface phases under numerous controlled conditions.

If the in-lab testing were to be performed again, a few changes should be made to the equipment and experiment testing procedure. A larger asphalt sample with more thermocouples to measure surface temperature would be built so that the laser and the IR temperature sensor would get their

Table 6-1: Summary of Experiment Results

Experiment		Temperature	Phase Change
1	Dry asphalt	▪ Air temperature off – initially overestimated, then underestimated ▪ Overestimated pavement temperature	▪ Correctly reported dry phase
2	Snow/Ice, Melt	▪ Air temperature reading increased more slowly than actual ▪ Overestimated pavement temperature	▪ Correctly reported snow to water phase change
3	Snow/Ice, Melt and Freeze	▪ Air temperature reading changed more slowly than actual ▪ Overestimated pavement temperature	▪ Correctly reported snow to water phase change ▪ Missed water to ice phase change
4	Snow/Ice, Melt and Freeze (with second puck)	▪ Air temperature reading changed more slowly than actual ▪ Overestimated pavement temperature	▪ Correctly reported snow to water phase change ▪ Missed water to ice phase change
5	Bubble-free Ice, Melt	▪ Air temperature reading changed more slowly than actual ▪ Pavement temperature accurate	▪ Confused phase change from ice to snow (slush) ▪ Correctly reported snow to water phase change
6	Spray, Freeze	▪ Air temperature reading changed more slowly than actual ▪ Slightly overestimated pavement temperature	▪ Correctly reported dry to water phase change ▪ Correctly reported water to ice phase change
7	Spray, Freeze and Melt	▪ Air temperature reading changed more slowly than actual ▪ Slightly overestimated pavement temperature	▪ Correctly reported dry to water phase change ▪ Correctly reported water to ice phase change with lag ▪ Correctly reported ice to water phase change

readings from the same asphalt sample. The experiments could be conducted over longer time periods to resemble the more typical, gradual temperature changes that produce phase change in the real world. Finally, more experiments could be performed to get a better idea as to the camera's reliability.

6.3. Next Steps

The findings from this in-lab experiment do not convey that the camera is ready for deployment. However, the results from the laboratory testing to date are robust enough that further in-lab testing is not deemed to be necessary in proceeding with this research project.

The next logical extension of this research is to test the camera in the real world environment but under controlled conditions. An experiment should be conducted using other types of pavement sensors and visual inspection to assess the IceSight's field accuracy. Ideally, a controlled condition would consist of mounting the camera on a pole at a similar height to the one planned for the final mounting of the IceSight. The camera should be aimed towards an outside asphalt test pad with the pavement sensor. This test site should be away from the road so the asphalt sample is not affected by traffic conditions. During a field test, a better assessment of the IceSight's air temperature accuracy can be gained because air temperatures will not be changing as drastically as the in lab testing. The results of this experiment should indicate whether the IceSight would be a suitable technology to replace or supplement current methods of detecting wintry road weather conditions.

An alternative direction for future research would be to conduct an in-lab assessment of phase changes as identified by the infrared camera against pavement sensors that are currently used by ODOT. However, since ODOT currently uses in-ground pavement sensors for winter maintenance and the testing of the infrared camera has shown promising results, this direction would not appear to have as much value.

Predicting surface conditions and phase change is difficult to do, and the IceSight camera system has shown promise that it can provide this valuable information to road maintenance agencies and staff.

REFERENCES

1. Innovative Dynamics Inc. *"Infrared Road Ice Detection System IRID Model B IceSight"* Users Reference Manual, Version 3.0, draft 12/14/2002.