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16. ABSTRACT

The California Department of Transportation (Caltrans) has contracted with the Western Transportation Institute (WTI) at Montana State University (MSU) to develop an "Automated Safety Warning Controller." The controller will interface with roadside devices such as sensors and signs. The controller will allow for automated data collection and application of best practice algorithms to analyze sensor data and to actuate related warning messages to motorists. For instance, wind warning messages might be actuated on a changeable message sign (CMS) when wind speed, as read from a sensor, exceeds a given threshold.

The controller allows for remote access and administration via standard IP-based connections established through POTS dialup or direct connection to wired access points, but is not dependent on those connections for operation. In other words, the controller will remain locally operable in the event that "outside" communication is unavailable for whatever reason. Even if a communication link to the outside is unavailable, the controller will continue to monitor and control its associated devices. This functionality is especially important in rural areas where weather conditions make communications services unreliable when the functionality is needed most. The standardized use of such a device would likely result in decreased maintenance costs, improved reliability, and greater flexibility in implementation when compared with "one-of-a-kind" deployments.

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DISCLAIMER STATEMENT

Automated Safety Warning Controller

Final Report

by

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A report prepared for the

State of California, Department of Transportation
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March 22nd, 2012

DISCLAIMER

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EXECUTIVE SUMMARY

The California Department of Transportation (Caltrans) has contracted with the Western Transportation Institute (WTI) at Montana State University (MSU) to develop an "Automated Safety Warning Controller." The controller will interface with roadside devices such as sensors and signs. The controller will allow for automated data collection and application of best practice algorithms to analyze sensor data and to actuate related warning messages to motorists. For instance, wind warning messages might be actuated on a changeable message sign (CMS) when wind speed, as read from a sensor, exceeds a given threshold.

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The purpose of this document is to present a summary of Phase 2 of this project.

1. INTRODUCTION

The purpose of this document is to present a summary of Phase 2 of the project to develop an Automated Safety Warning Controller.

1.1. Project Goals

The primary goal of this project was to develop an Automated Safety Warning System Controller that will interface with roadside devices such as sensors and signs. The controller will allow for automated data collection and application of best practice algorithms to analyze sensor data and to actuate related warning messages and signals. For instance, wind warning messages might be actuated on a changeable message sign (CMS) when wind speed, as read from a sensor, exceeds a given threshold. The controller system has been designed for flexibility and extensibility, allowing for the integration and control of a variety of roadside devices. As such, it could be used as a standardized component with widespread applicability.

The end product of this project is a prototype hardware and software system that has been tested in the field.

1.2. Project Tasks

The work plan for Automated Safety Warning Controller consisted of the following eight tasks:

- Task 1: Project Management
- Task 2: Review Phase 1 Results
- Task 3: On-Going Development
- Task 4: Pilot Testing
- Task 5: Business Case Development
- Task 6: Evaluation

1.3. Report Organization

This report presents a summary of activities from the Automated Safety Warning Controller effort. As Project Management activities encompassed work related to budget maintenance, communications with the project sponsor, scheduling and the like, a discussion of the work completed for that specific task has been excluded. Remaining chapters of this report will summarize each of the remaining tasks listed above. A more comprehensive discussion of each task can be found in the deliverable document(s) associated with the task.

1.4. System Concept

Current practice for setting and activating CMS, EMS, and flashing beacon signs involves manual operation from the rural traffic management center (RTMC). Data from field elements such as RWIS and loop detectors is retrieved by a RTMC operator, who decides whether the data from the field elements warrants activation of a CMS, EMS, or flashing beacon. The speed of this process is subject to the efficiency of the RTMC operator at retrieving data from numerous locations and deciding where, if at all, to activate a warning or information system. Further impacting this process is the fact that a RTMC is generally not manned 24 hours per day, so there may be "off hours" in which there is further delay in activating warnings or information systems. Furthermore, communication lines are often unreliable in rural areas, particularly during a severe weather event, making communication with field elements unpredictable.

The goal of this project was the development of a system that frequently and automatically monitors field element data and determines, according to best practice algorithms, if a warning should be activated. The automated warning controller device would be installed near the warning devices it controls, so the system could continue to work even if communication with the RTMC is disrupted. The controller can also poll field elements much more frequently than a RTMC operator and quickly and automatically make the decision whether to activate a warning based on the retrieved information. Another goal of this project was to develop a standardized system that is versatile enough to be used at any location, with any number and type of field elements from which to draw data. Figure 1 shows an early conceptual diagram of the system.

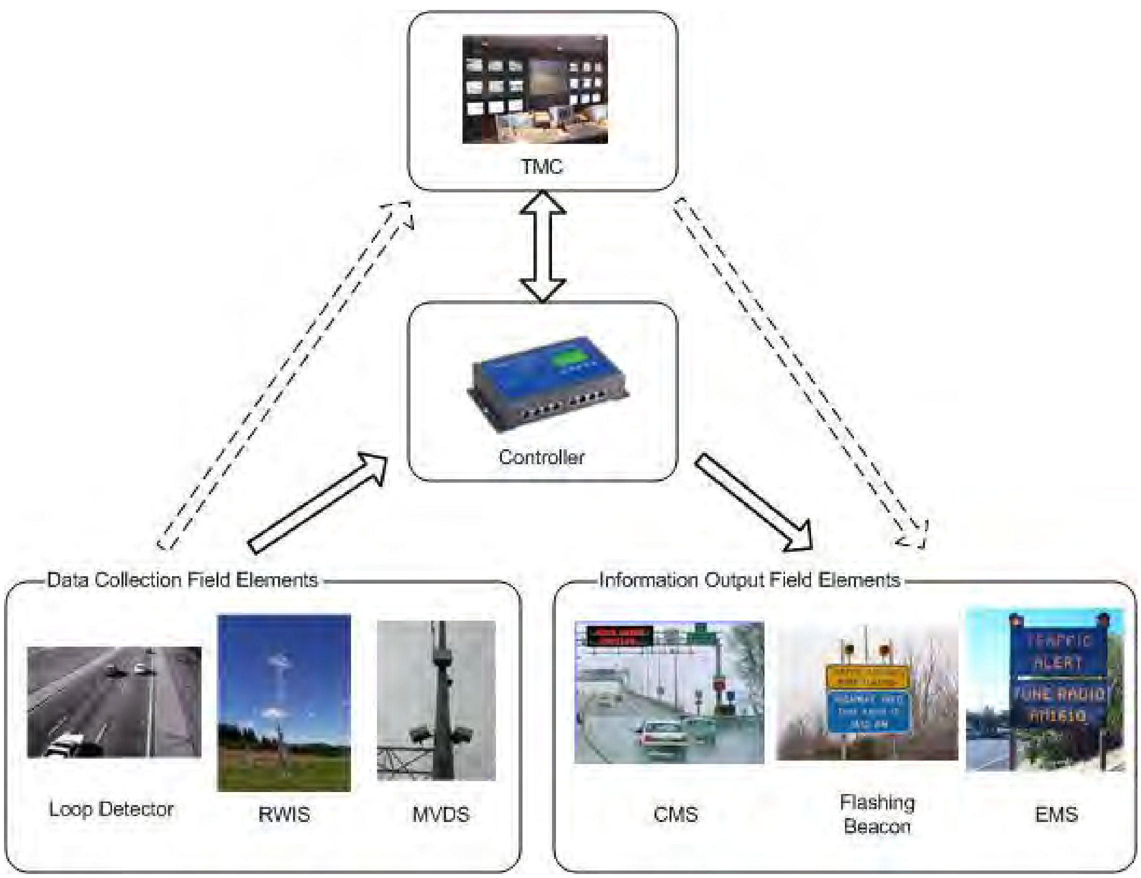

Figure 1: Controller Interaction with TMC and Field Elements

2. REVIEW PHASE 1 RESULTS

The major outcome of Phase 1 of the Automated Safety Warning System Controller project was a pilot system running at the Caltrans District 2 Spring Garden site. The pilot system has been running since mid-August 2009 with minimal supervision and few issues. The pilot system was running an ice warning alert script. An additional system has been running in the District 2 lab where further testing was taking place. The testing at both the pilot site and the District 2 lab revealed a few minor issues and a few desired modifications and improvements. In addition to issues found during testing, items that were not completed during Phase 1 were identified.

One concern with the Phase 1 system was the form factor of the Moxa device used. For Phase 2 a rack mount device that is consistent with Caltrans roadside network equipment mounting would be chosen.

Other issues that were identified during the Phase 1 testing included:

- A problem with the auto archiving of data files that was causing the working file to grow large and was impacting system performance.
- In the lab setting it was noticed that when the CMS module was unable to connect to the CMS the first time that the retries didn't appear to be working.
- The organization of the data files should be improved for readability. Currently the order of the fields in the csv files is somewhat arbitrary; a better organization would make analyzing the data files easier.
- The front panel interface should be improved to make it intuitive when used infrequently in a side of the road environment and give an acknowledgement of all commands. The interface will need to be re-worked for the smaller screen size and fewer buttons of the DA-661.

The primary item not completed during Phase 1 was a Satellite Operations Center Command System (SOCCS) style interface for TMC personnel to monitor and control the ASWC.

For a complete list of the Phase 2 recommendations see Automated Safety Warning Controller Phase 2 Review Summary and Recommendations (1).

3. ON-GOING DEVELOPMENT

The first step in the ongoing development was to review the complete code base with the goal of improving the efficiency, reliability, and maintainability of the code base. During the cycle of bug fixes and feature requests that happen as part of the pilot testing it is easy for the code base to become fragmented so a complete code review is a good first step prior to further development. Modules were refactored to improve memory consumption and readability.

Next the issues that were identified as problems in the Phase 1 testing were fixed and interim versions of the code sent to Caltrans District 2 for testing in the lab.

For this phase of the project, Caltrans requested the use of a rack mount device consistent with Caltrans roadside network equipment mounting. The Moxa DA-661 was selected due to its compatibility with the UC-7420 used in Phase 1. Figure 2 shows the Moxa DA-661.

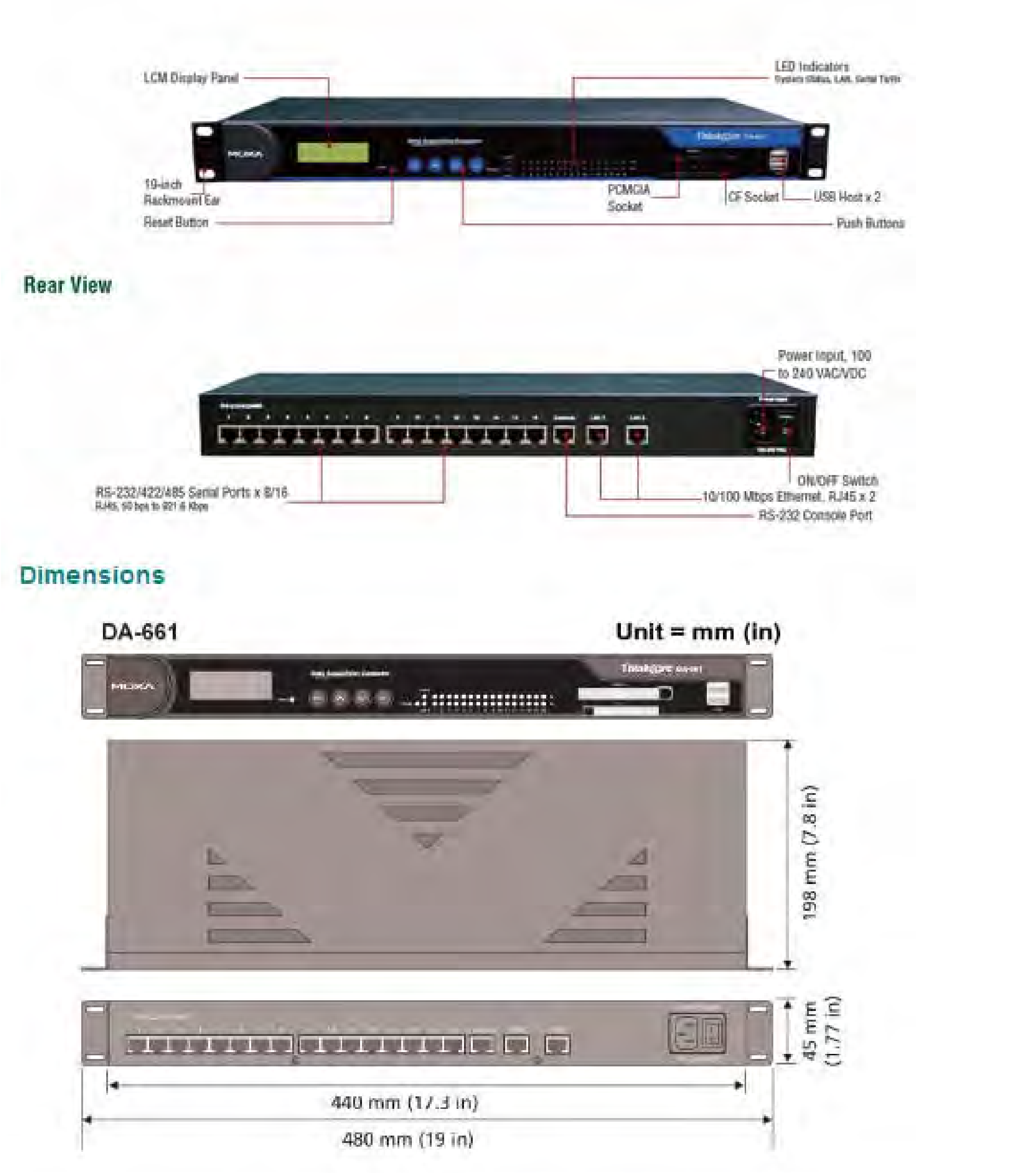

Figure 2: Moxa DA-661 Embedded Computer (image courtesy of Moxa)

The main difference between the UC-7420 used in Phase 1 and the DA-661 is the size of the display and number of front panel buttons. Improving the front panel interface was one of the items identified from Phase 1, modifying it for the fewer buttons and smaller display size of the DA-661 added to the challenge of making an informative and intuitive interface. The front panel interface was re-done to be easy to understand and use for the occasional user such as a field technician doing periodic maintenance on a site. It implements a positive feedback acknowledgement of all commands.

To support the development of the Satellite Operations Center Command System (SOCCS) ASWC interface a controller message protocol was defined and documented. After review, the server side of the protocol was implemented as a module within the ASWC system. The client side of the protocol was then developed as part of the SOCCS ASWC user interface. For more information on the controller message protocol see Controller Message Protocol Definition Document (2)

The SOCCS ASWC user interface was implemented as a Java applet running on a PC browser and served up by a separate TMC housed server. The SOCCS ASWC user interface was implemented as a summary screen and administrative screen. Multiple ASWCs can be configured and will be listed on the summary screen. The summary screen gives a quick look at the status and CMS message(s) for the configured ASWC, see Figure 3. The summary screen establishes an unauthenticated connection with the ASWC, retrieves the status and CMS message data, and then closes the connection. The update interval is configurable to optimize the usage of dialup lines. The administrative screen is accessed by demand and requires a username/password combination to establish an authenticated connection with the ASWC. The administrative screen gives operator and supervisor level access to the ASWC as defined in the Automated Safety Warning Controller System Concept and Requirements Specification (3). This screen allows the user to view detailed status of the running modules, view log messages, view values of input module sensors, and add a message to the CMS.

Figure 3: SOCCS ASWC Summary Screen

A few issues with the Moxa devices were discovered during the Phase 2 testing that required time to characterize and resolve. Problems working with Moxa's support led to some questioning of the reliability of the devices and the feasibility of using the devices in the long term. The following outlines these issues.

Compact Flash Card Compatibility

The Phase 1 ASWC ran on a Moxa UC-7420 with an added SanDisk Ultra II 4GB compact flash card. The compact flash card is used to store the ASWC code and all the data and log files. Initially the Moxa DA-661 was tested with the same compact flash card as used in Phase 1 on the UC-7420 and testing went well. Additional DA-661s were purchased to send to Caltrans District 2 for testing and newer models of the same SanDisk card were purchased and included. Comprehensive testing was started in the Caltrans District 2 lab where some failures started appearing. At random times the CF card would enter an error state that would be unrecoverable. WTI proceeded to run some stress tests on the compact flash cards using both the UC-7420 and the DA-661. The CF cards would pass on when formatted as vfat but have random failures on both devices when formatted as ext2. A trouble ticket was opened with Moxa technical support with the response being that they have seen issues with Sandisk Cards. Moxa technical support recommended other CF cards including the Transcend TS4GCF150. The Transcend card was purchased and tested by WTI with the cards showing similar failures when formatted ext2. Further back and forth with Moxa technical support occurred to convince them that there was an issue with the Transcend cards. The Moxa response was to recommend a different CF card at which point WTI and Caltrans escalated the issue with Moxa to get a satisfactory resolution. A Moxa embedded computing engineer responded that firmware on different versions of CF cards causes Moxa to retest and recertify CF cards that will work with their devices. They now recommended an Innodisk ICF 4000 4GB card and offered to create a part number that would include the DA-661-lx with the approved CF card. Testing of the new CF cards proved successful. and 10 of these cards were purchased for use with the ASWC.

Clock Timing Issue

While trying to resolve the compact flash card issues with the Moxa DA-661 it was discovered that Caltrans District 2, using the DA-661 for other applications, had found a significant clock drift problem with the device. Tests run by WTI on a DA-661 as it was received from the factory (firmware version 1.5 build 08040117) revealed a software clock drift of up to 35 seconds per hour. Note that the hardware clock on the device appeared to show little or no drift. Discussions with Moxa were able to bypass technical support and go right to the embedded computing engineer who suggested we upgrade to the latest version of firmware (v 1.6 build 10070920) as the clock drift was a known problem that was fixed in this latest release. The latest version of the firmware was installed on a DA-661 in the WTI lab showed very little clock drift, no more than 1 second per hour) depending on the current workload.

Moxa Alternatives

There were significant enough problems in dealing with Moxa support in trying to resolve the issues above to initiate conversations about alternative devices. A search revealed that alternative devices are out there including some of the advanced transportation controllers that are specifically designed for transportation applications. Although none of these devices stood out as an obvious, immediate replacement for the Moxa DA-661 there are enough alternatives to warrant further investigation should it become desirable to discontinue use of the Moxa.

Items not completed

Some items not accomplished as part of Phase 2 include:

- Full testing of additional field elements. Modules have been created and tested internally for loop detectors, MVDS, RTMS, and WebRelay for EMS beacon; however further near real world testing is necessary to certify these modules as complete.
- Investigation of additional applications. The flexibility of the ASWC design can lend its use to a variety of applications including near real time applications such as ramp metering and speed warning however time did not allow for investigating or implementing additional applications.

For a complete description of the development done during Phase 2 see the Automated Safety Warning Controller System Development Summary (4).

4. PILOT TESTING

Testing of the controller system involved unit tests of each module, integration tests of the controller system as a whole, and long-term reliability tests. The testing under Phase 2, similar to Phase 1 took place in the WTI lab as well as the Caltrans District 2 lab. Do to time constraints the pilot testing either as a replacement for the phase 1 system at the Caltrans Spring Garden site or at an alternate site was not completed.

In-lab testing both at WTI and Caltrans District 2 was done with issues found and fixed. In addition to the ice warning script that has been running on the Phase 1 ASWC at the Caltrans Spring Garden site, wind warning scripts were tested successfully at WTI and the District 2 lab. Data from the Phase 1 Spring Garden site and the Phase 2 system running in the Caltrans District 2 lab was analyzed to be sure both systems were operating as designed.

Time was spent trying to test and characterize the Moxa compact flash card issue and work with Moxa to find an adequate solution.

Issues were found with the software clock on the Moxa DA-661 being used, additional testing was done to certify this problem was fixed with a new version of the Moxa firmware.

The SOCCS ASWC interface was new to this phase and required a significant amount of testing. After some initial testing at Caltrans District 2, Joe Baltazar from the District 2 TMC requested a system to allow TMC messages and ASWC messages to co-exist on a CMS. Changes were made to the CMS module of the ASWC and the SOCCS interface to support this additional functionality. A new cycle of testing at WTI and Caltrans was then started and continued until the system was running reliably. Careful attention was paid to the interaction of TMC initiated CMS messages and ASWC CMS messages.

The testing plan and procedures have been documented in Automated Safety Warning Controller System Testing Plan and Summary and System Evaluation Plan and Summary (5).

5. BUSINESS CASE DEVELOPMENT

Business case development was not addressed in this Phase of the project.

6. EVALUATION

Evaluation of the system's technical performance was performed for the Phase 1 system running at the Spring Garden pilot location as well as the Phase 2 system running in the Caltrans District 2 lab. Several data and log files that included a time period in which the weather should have triggered an alert were retrieved from both devices and sent back to WTI for evaluation. Inspection of the files showed that both the Phase 1 system and the Phase 2 system were working as they should; a CMS message was properly generated by the alert script and was placed on the sign without error.

Reliability was evaluated by unsupervised tests of at least several months in duration. This included both in-lab and in-field tests. The Spring Garden device has been running continuously at the pilot location for over three years at the time of this writing and continues to work properly and without error. None of the Phase 2 in-lab systems have been tested continuously for as long, but they also continue to operate reliably and without error.

Usability evaluation was accomplished through a list of survey questions sent to Joe Baltazar of Caltrans District 2 TMC and Jeff Worthington of Caltrans District 2 engineering. The usability evaluation of the SOCCS ASWC interface was somewhat limited as it was only interacting with the test device in the District 2 lab, however some valid comments were given and overall the system was expected to be helpful. Comments regarding the changes made to the front panel interface were positive. The evaluation plan and procedures have been documented in Automated Safety Warning Controller System Testing Plan and Summary and System Evaluation Plan and Summary (5).

The Caltrans District 2 Spring Garden site, east of Quincy on SR-70, has served as a pilot test site for the project since Phase 1. The Phase 1 system has been running at Spring Garden since mid-August 2009. The Phase 2 system has not yet been installed at Spring Garden, so recent data from the Phase 1 system is presented here.

Figure 4: Spring Garden Location

There is an RWIS at the Spring Garden with six in-pavement surface sensors deployed at three locations spanning approximately one-half mile. The West CMS is one-half mile west of the first surface sensor and the East CMS is a little over one-half mile east of the last surface sensor.

Figure 5: Spring Garden Field Element Configuration

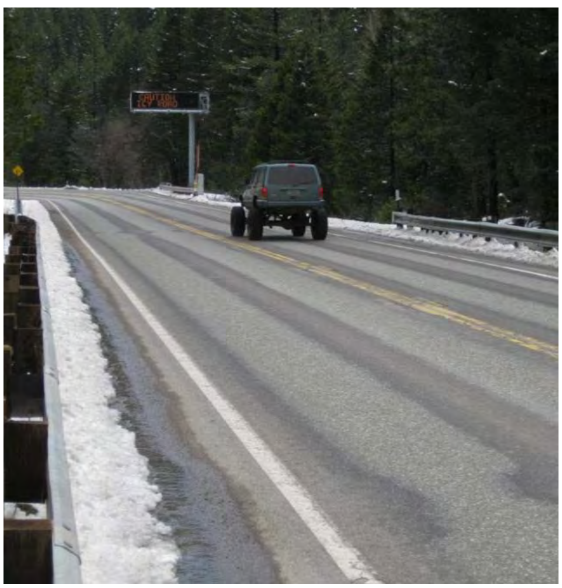

Figure 6: Eastbound CMS (photo by Ian Turnbull)

Figure 7: Westbound CMS (photo by Ian Turnbull)

Figure 8: Pavement Surface Sensors

Figure 9: Spring Garden RWIS (photo by Ian Turnbull)

Figure 10: Pavement Surface Sensor

Figure 11: ASWC in Spring Garden ITS Cabinet, as shown by Ian Turnbull

An ice warning alert was implemented at this site using the ASWC to warn drivers from either direction of ice on the road in the section covered by the surface sensors, which is generally shaded and along a slope where runoff occurs. The roadway prior to this section may be bare and dry while this section has ice due to runoff and cooler temperatures.

The following photos from Google Street View from February 2009 traverse this segment from West to East, and demonstrate this condition, with a bare and dry roadway preceding and following the segment and apparent ice on the segment.

Figure 12: Google Street View Images of Spring Garden ASWC Ice Warning Area (Part 1)

Figure 13: Google Street View Images of Spring Garden ASWC Ice Warning Area (Part 2)

Figure 14: Google Street View Images of Spring Garden ASWC Ice Warning Area (Part 3)

The alert logic for the icy road warning at Spring Garden checks the NTCIP surface status codes for Ice Warning, Ice Watch or Frost. If any of these are present for any of the of surface sensors, then a warning message will be triggered. Further, if the surface status code indicates Wet and the temperature is below 32.5° F, then a warning message will be triggered:

```
SurfaceIceWarning = RWIS.essSurfaceStatus1()==ICEWARN or
                    RWIS.essSurfaceStatus2()==ICEWARN or
                    RWIS.essSurfaceStatus3()==ICEWARN or
                    RWIS.essSurfaceStatus4()==ICEWARN or
                    RWIS.essSurfaceStatus5()==ICEWARN or
                    RWIS.essSurfaceStatus6()==ICEWARN

SurfaceIceWatch = RWIS.essSurfaceStatus1()==ICEWATCH or
                  RWIS.essSurfaceStatus2()==ICEWATCH or
                  RWIS.essSurfaceStatus3()==ICEWATCH or
                  RWIS.essSurfaceStatus4()==ICEWATCH or
                  RWIS.essSurfaceStatus5()==ICEWATCH or
                  RWIS.essSurfaceStatus6()==ICEWATCH

SurfaceFrost = RWIS.essSurfaceStatus1()==FROST or
               RWIS.essSurfaceStatus2()==FROST or
               RWIS.essSurfaceStatus3()==FROST or
               RWIS.essSurfaceStatus4()==FROST or
               RWIS.essSurfaceStatus5()==FROST or
               RWIS.essSurfaceStatus6()==FROST

SurfaceSnow = (RWIS.essSurfaceStatus1()==WET and SurfTemp1 < 32.5) or
       (RWIS.essSurfaceStatus2()==WET and SurfTemp2 < 32.5) or
       (RWIS.essSurfaceStatus3()==WET and SurfTemp3 < 32.5) or
       (RWIS.essSurfaceStatus4()==WET and SurfTemp4 < 32.5) or
       (RWIS.essSurfaceStatus5()==WET and SurfTemp5 < 32.5) or
       (RWIS.essSurfaceStatus6()==WET and SurfTemp6 < 32.5)

if SurfaceIceWarning or SurfaceIceWatch or SurfaceFrost or SurfaceSnow:

    CMSEast.MessagePage1Line1 = "CAUTION"
    CMSEast.MessagePage1Line2 = "ICY ROAD"

    CMSWest.MessagePage1Line1 = "CAUTION"
    CMSWest.MessagePage1Line2 = "ICY ROAD"
```

Figure 15: Abbreviated Alert Logic for Icy Road Warning at Spring Garden

The project team examined in detail the operation of the ASWC throughout December 2012 to verify that warning messages were invoked during conditions matching the alert logic. The following plots show this analysis and confirm correct operation of the ASWC. Note that times and day breakdowns correspond to GMT.

During the first seven days, no warning messages were displayed. Although several of the sensors detected "Wet" condition, temperatures were above freezing. On the 8th through 10th days, the warning message was triggered due to primarily to Ice conditions (Ice Warning, Ice Watch or Frost). When temperatures rose above freezing, the warning message was taken off the sign. At the end of the 8th day and throughout the entire 9th and 10th days Ice conditions were present and the warning message was displayed. Note that the "Snow" condition, which corresponds to "Wet" and temperature below 32.5 degrees was intermittent during this time. Ice conditions were reported on as many as 5 of the sensors during this time. Note further that one of the surface sensors was reported invalid values, so these summaries only include five of the surface sensors.

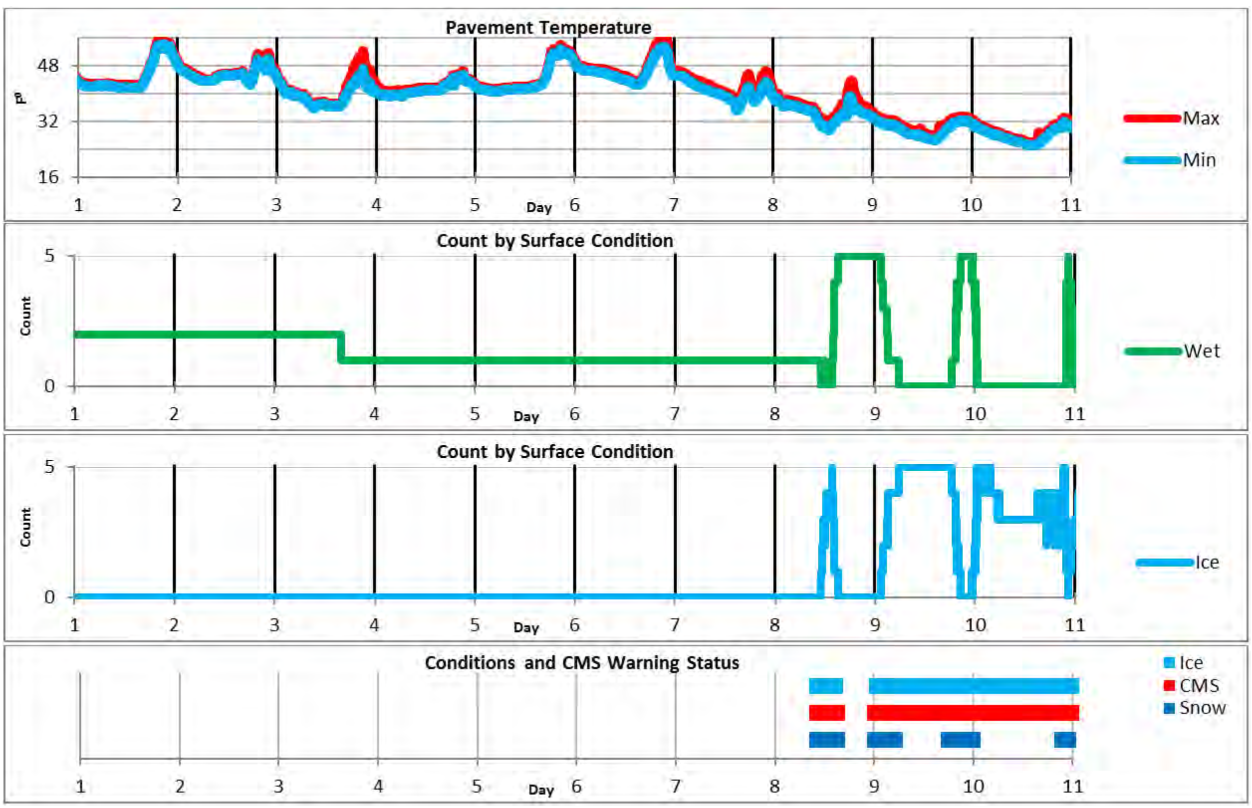

Figure 16: Conditions and Warning Status for 2012-12-01 through 2012-12-10 GMT (pavement temperatures in °F, "Count" is the number of sensors reporting the given conditions)

Warning messages were invoked over most of the 11th through 20th days, with the exception of most of Day 17, when temperatures were above freezing. Note that several times, particularly at the end of day 11 and the beginning of Day 12, Ice conditions were not present but snow conditions were. During days 15 and 18, Snow conditions caused the warning message to remain on the signs during short periods in which ice conditions were not reported.

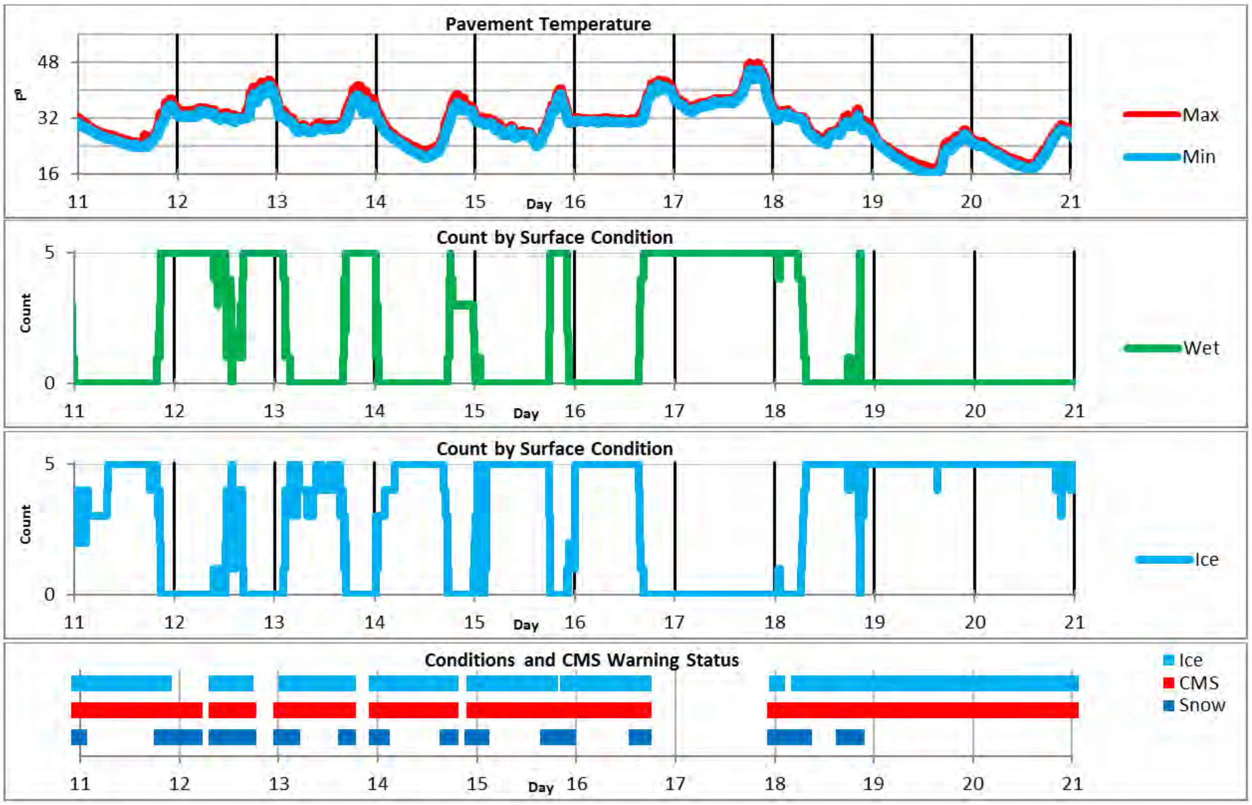

Figure 17: Conditions and Warning Status for 2012-12-11 through 2012-12-20GMT (pavement temperatures in ^{o}F, "Count" is the number of sensors reporting the given conditions)

Days 21 through 30 showed similar behavoir, with warning messages active for all but a short interval on Day 26, another on Day 29, and a very short time on Day 30.

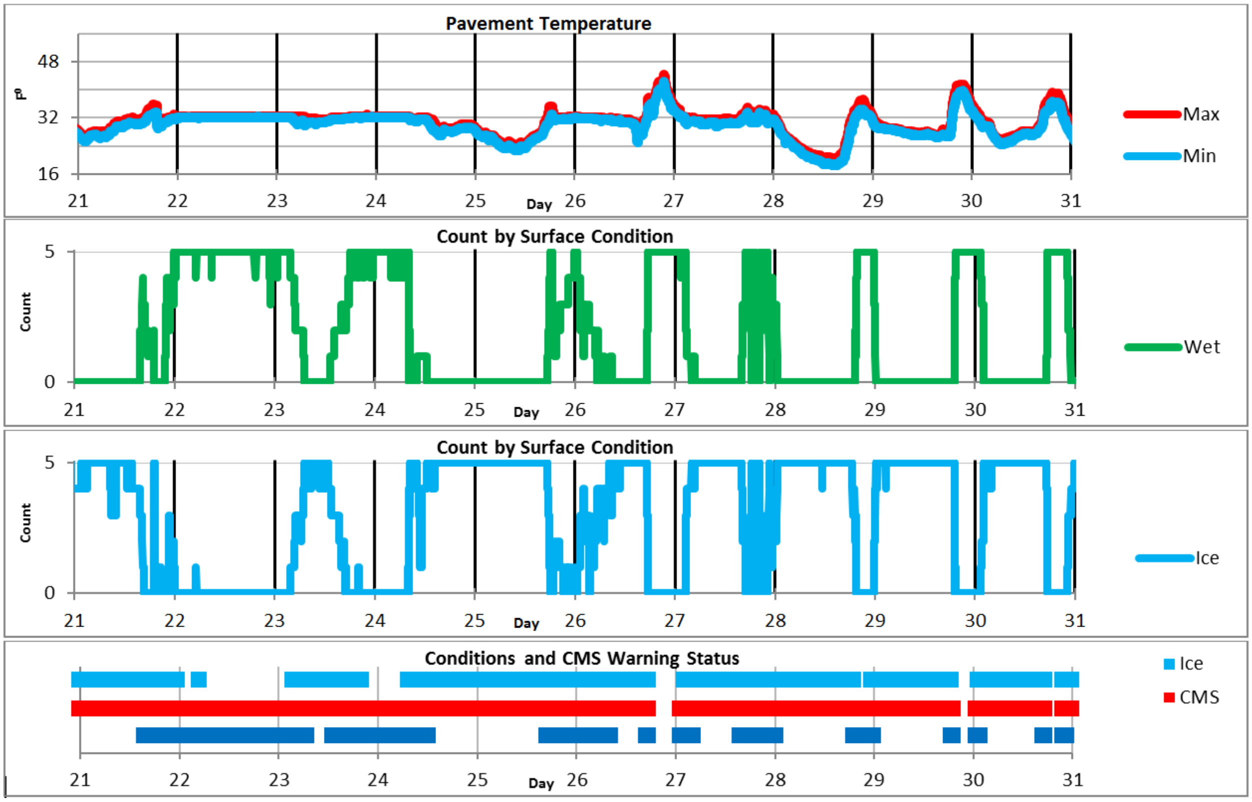

Figure 18: Conditions and Warning Status for 2012-12-21 through 2012-12-30GMT (pavement temperatures in °F, "Count" is the number of sensors reporting the given conditions)

The following CCTV images and graphs corresponding to daylight hours and allow for visual confirmation of the conditions at Spring Garden. Generally the CCTV images confirm the conditions, although it is difficult at times to determine from the images alone whether there is ice on the roadway. It is particularly interesting to observe the times in which conditions were changing from Ice to Wet and versa, including times when there is snow on the road, but ice conditions are not detected. For the latter, the additional logic used by Caltrans District 2 to represent "Snow" conditions appear to be merited, particularly during transition times which might otherwise result in no warning messages.

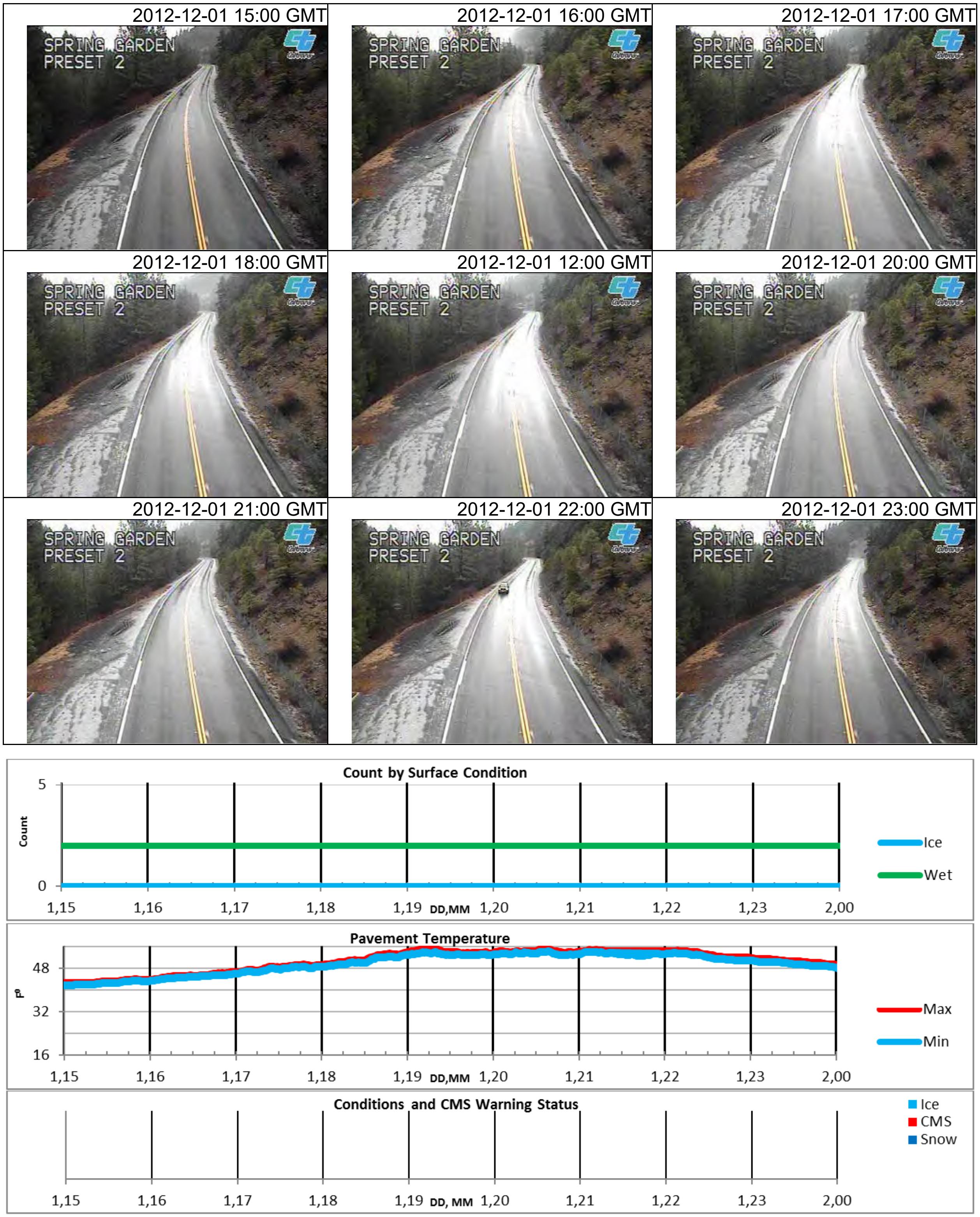

Figure 19: Conditions and Warning Status for 2012-12-01 GMT (pavement temperatures in ^{o}F, "Count" is the number of sensors reporting the given conditions)

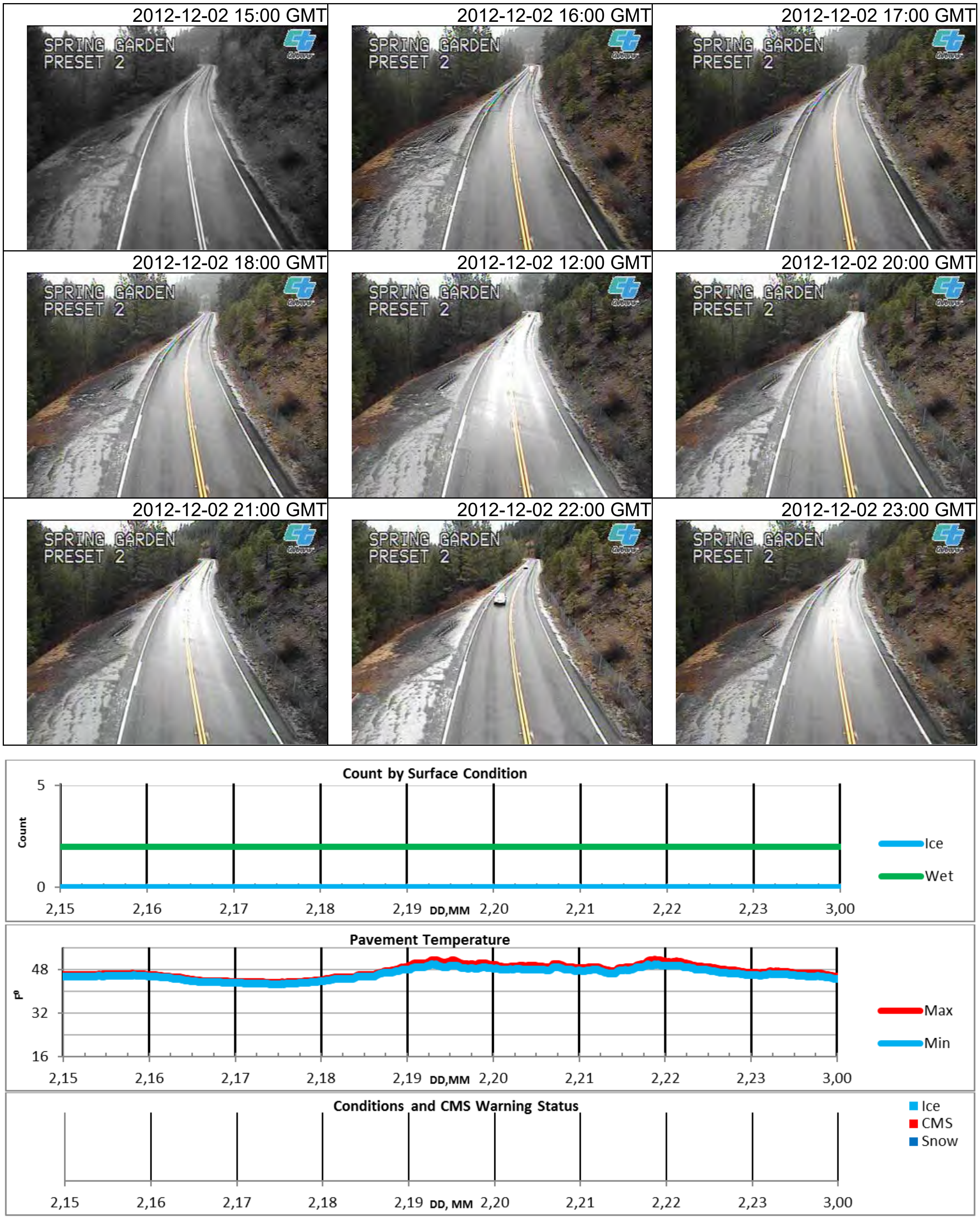

Figure 20: Conditions and Warning Status for 2012-12-02 GMT (pavement temperatures in °F, "Count" is the number of sensors reporting the given conditions)

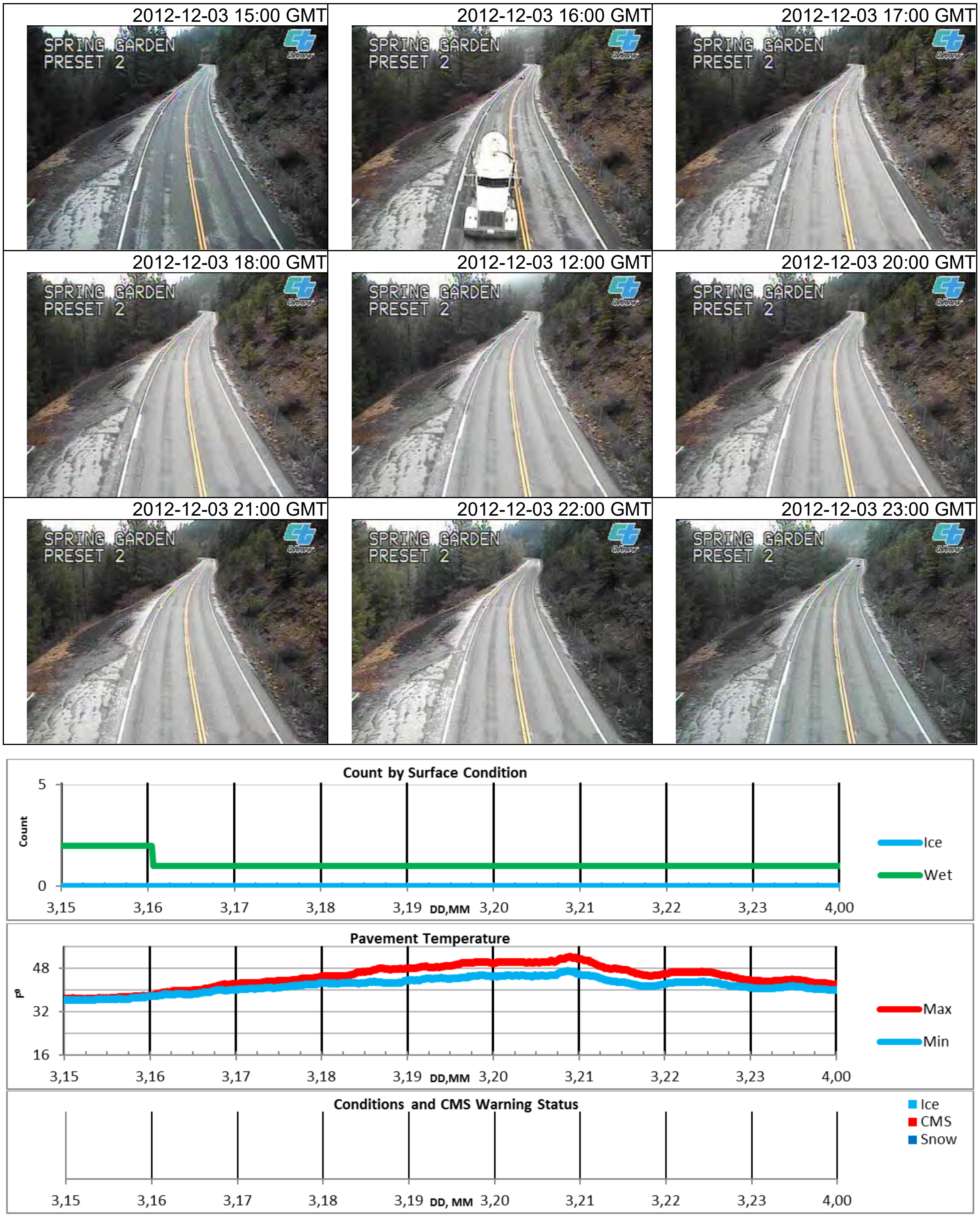

Figure 21: Conditions and Warning Status for 2012-12-03 GMT (pavement temperatures in °F, "Count" is the number of sensors reporting the given conditions)

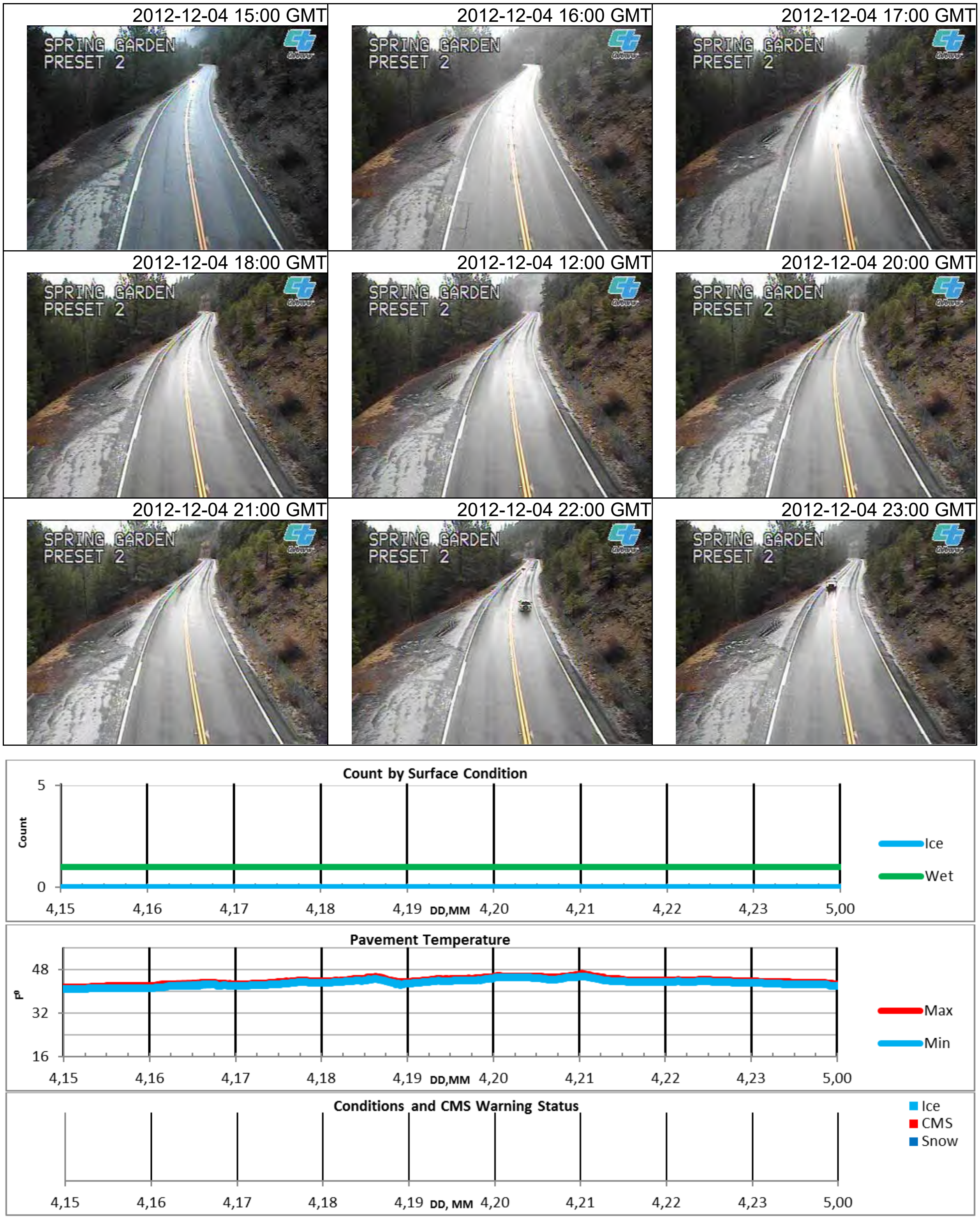

Figure 22: Conditions and Warning Status for 2012-12-04 GMT (pavement temperatures in °F, "Count" is the number of sensors reporting the given conditions)

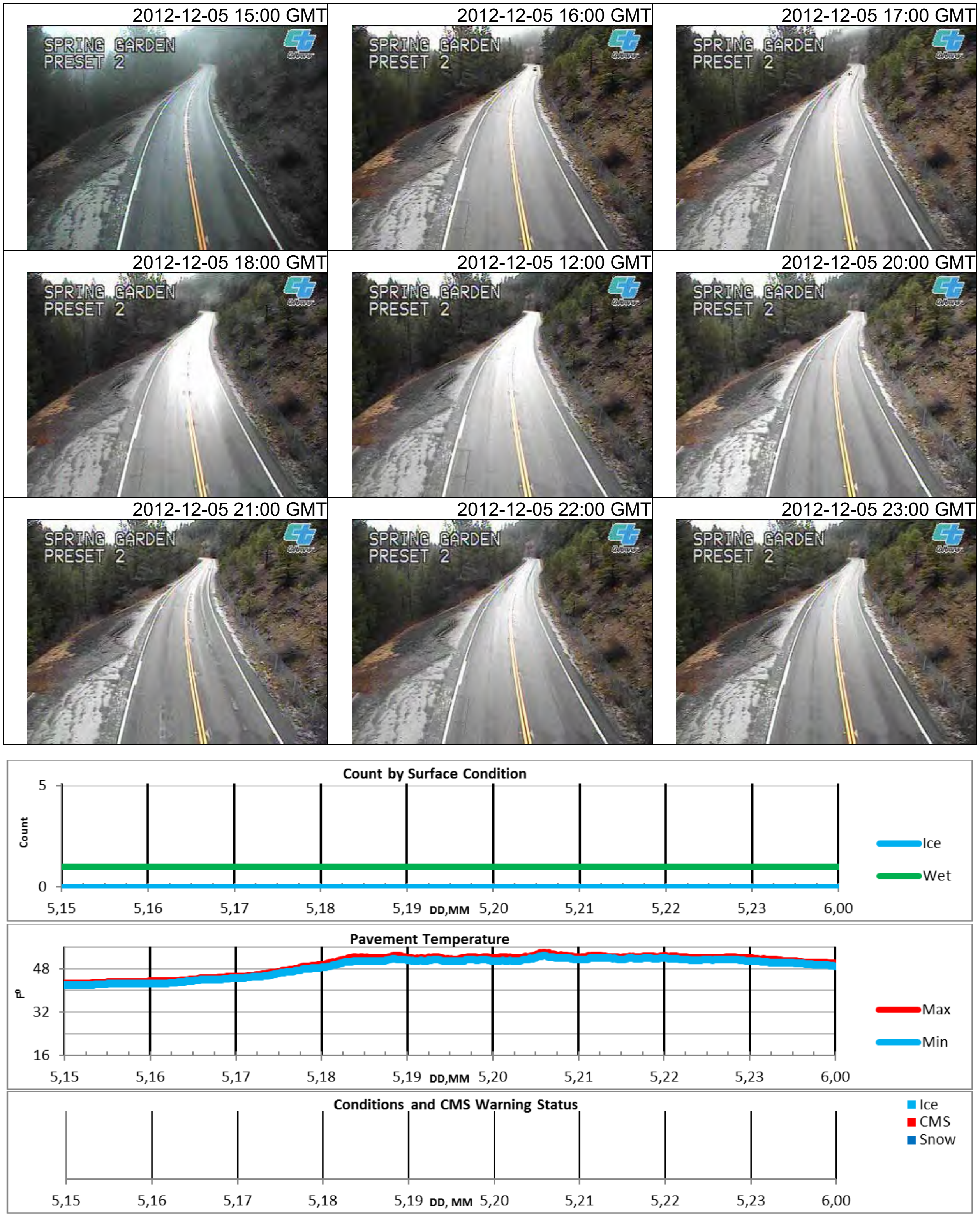

Figure 23: Conditions and Warning Status for 2012-12-05 GMT (pavement temperatures in °F, "Count" is the number of sensors reporting the given conditions)

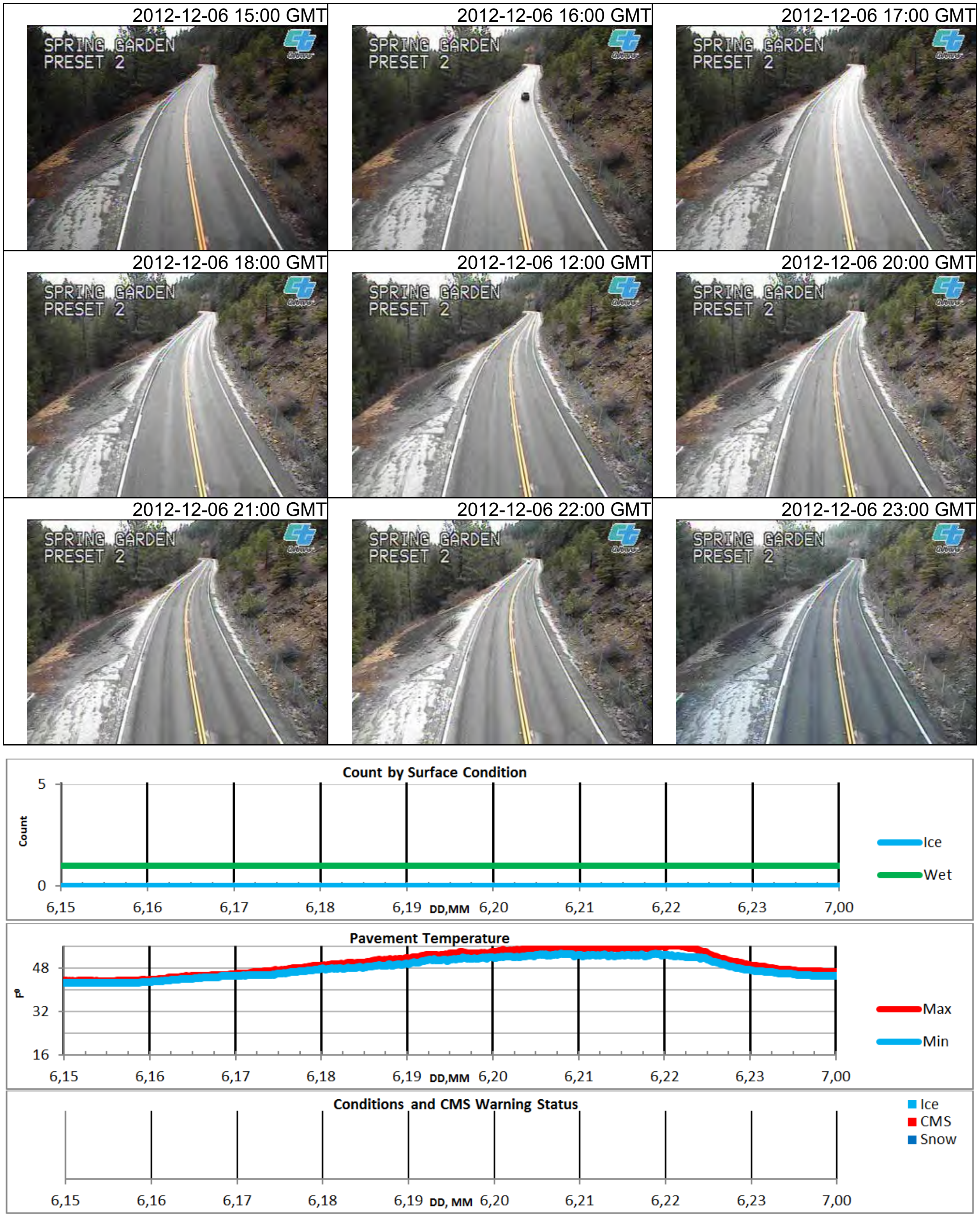

Figure 24: Conditions and Warning Status for 2012-12-06 GMT (pavement temperatures in °F, "Count" is the number of sensors reporting the given conditions)

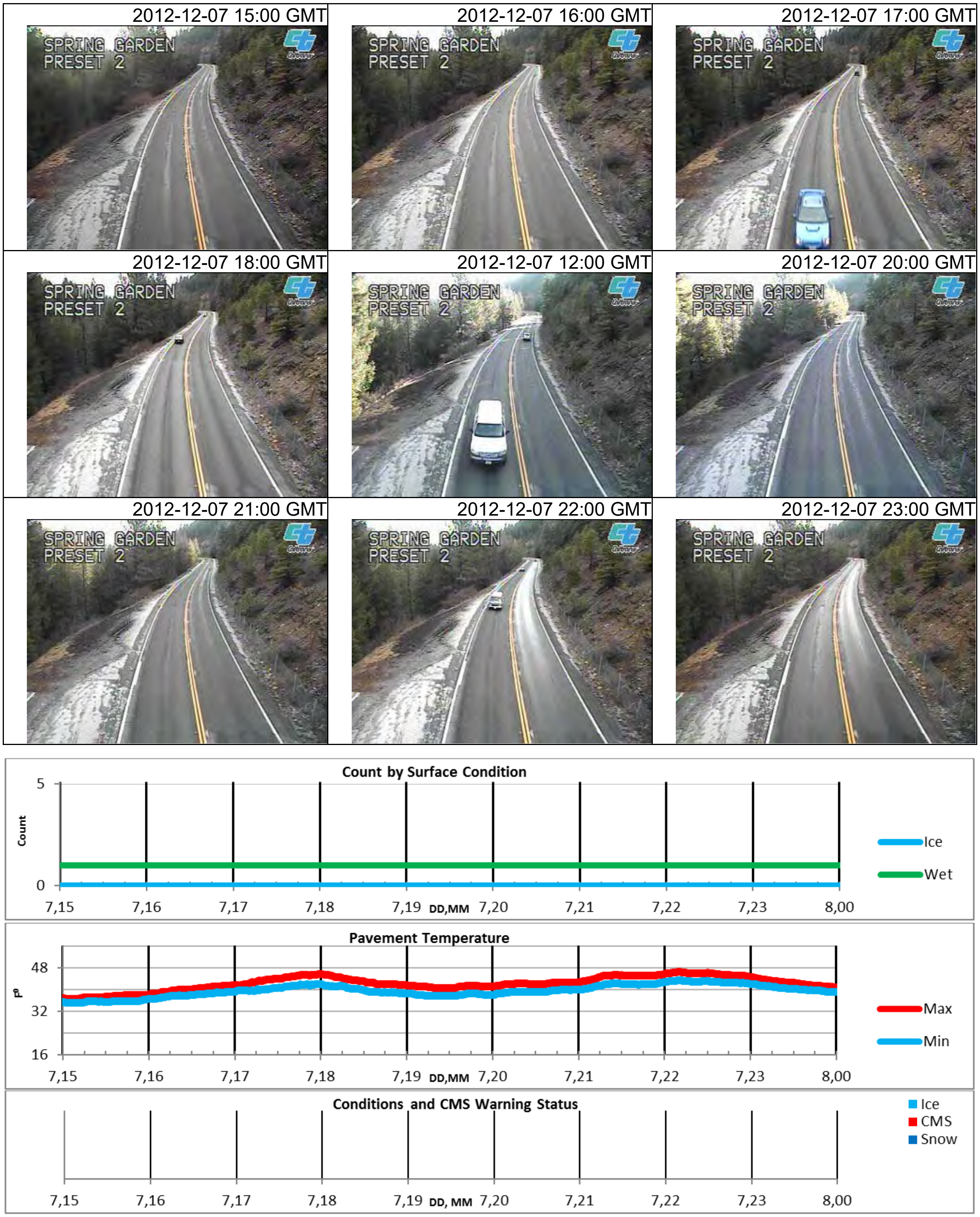

Figure 25: Conditions and Warning Status for 2012-12-07 GMT (pavement temperatures in ^{o}F, "Count" is the number of sensors reporting the given conditions)

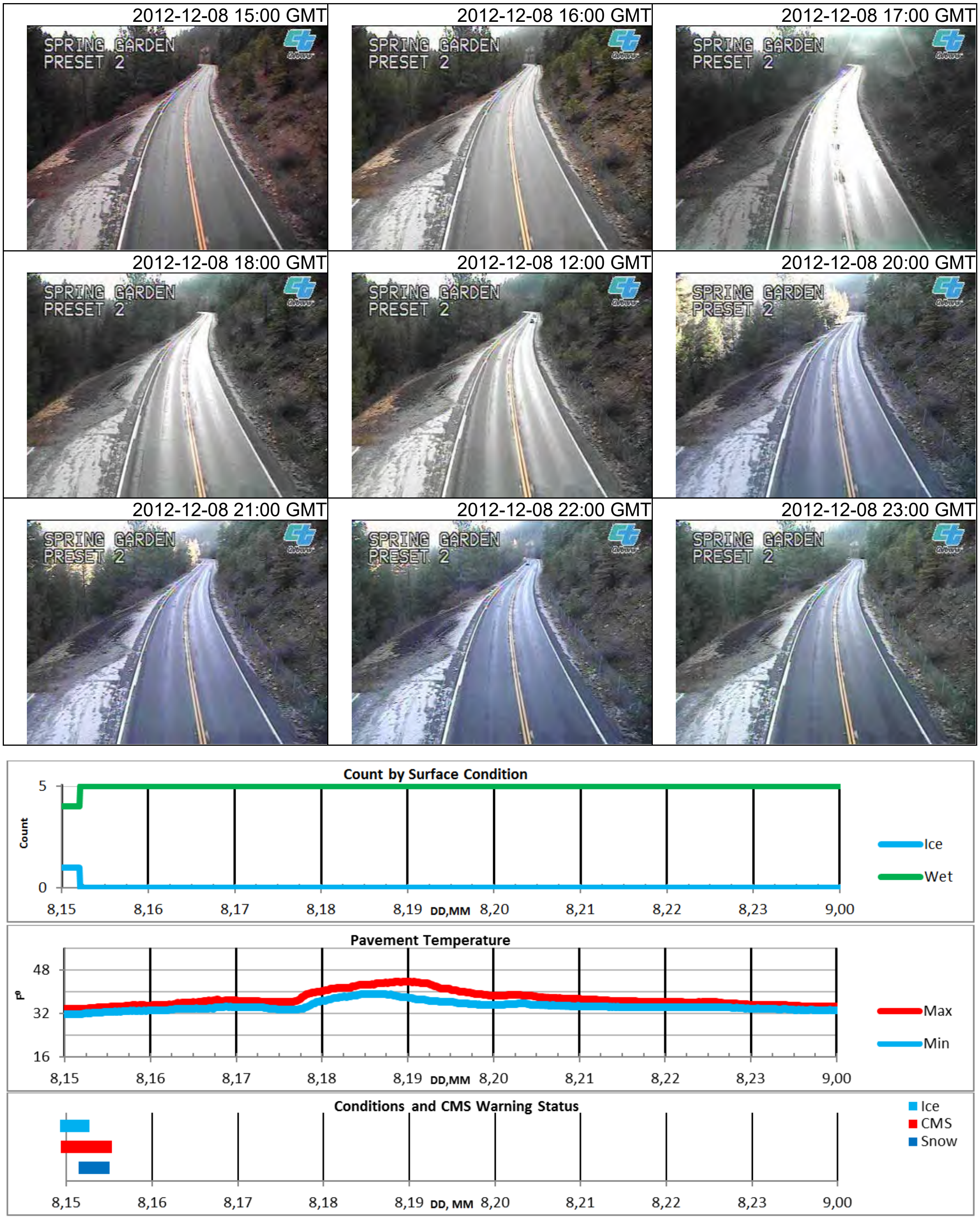

Figure 26: Conditions and Warning Status for 2012-12-08 GMT (pavement temperatures in ^{o}F, "Count" is the number of sensors reporting the given conditions)

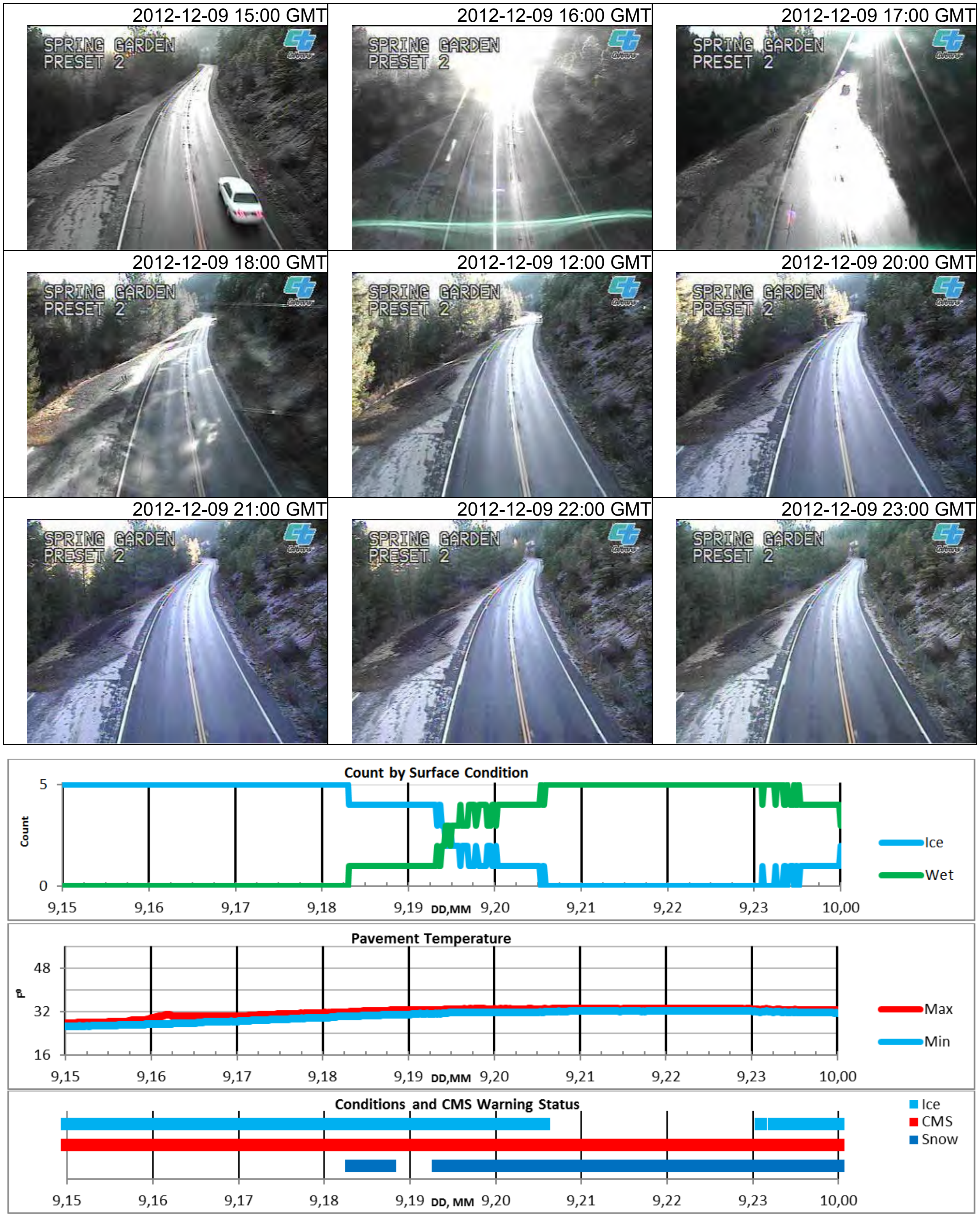

Figure 27: Conditions and Warning Status for 2012-12-09 GMT (pavement temperatures in ^{o}F, "Count" is the number of sensors reporting the given conditions)

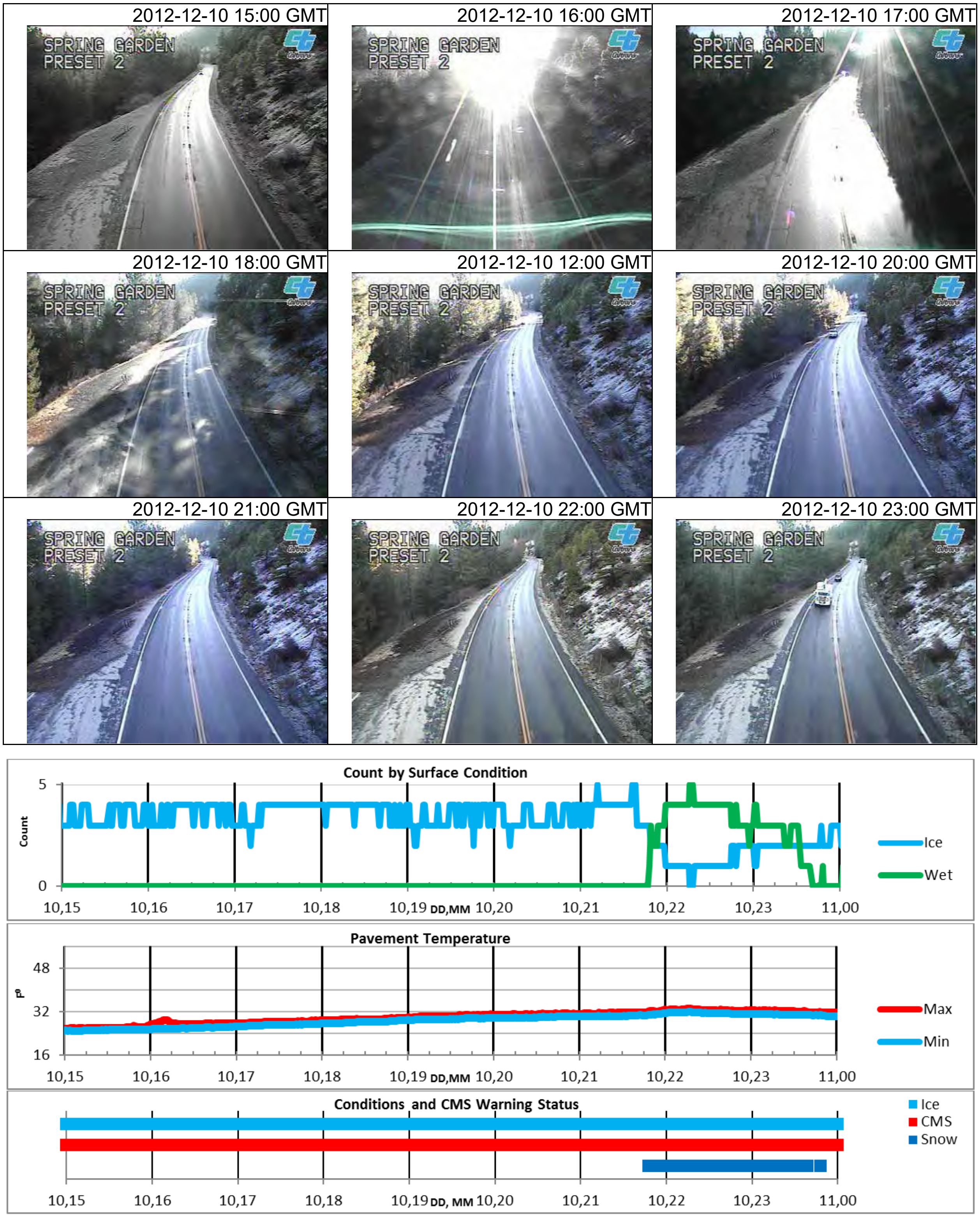

Figure 28: Conditions and Warning Status for 2012-12-10 GMT (pavement temperatures in ^{o}F, "Count" is the number of sensors reporting the given conditions)

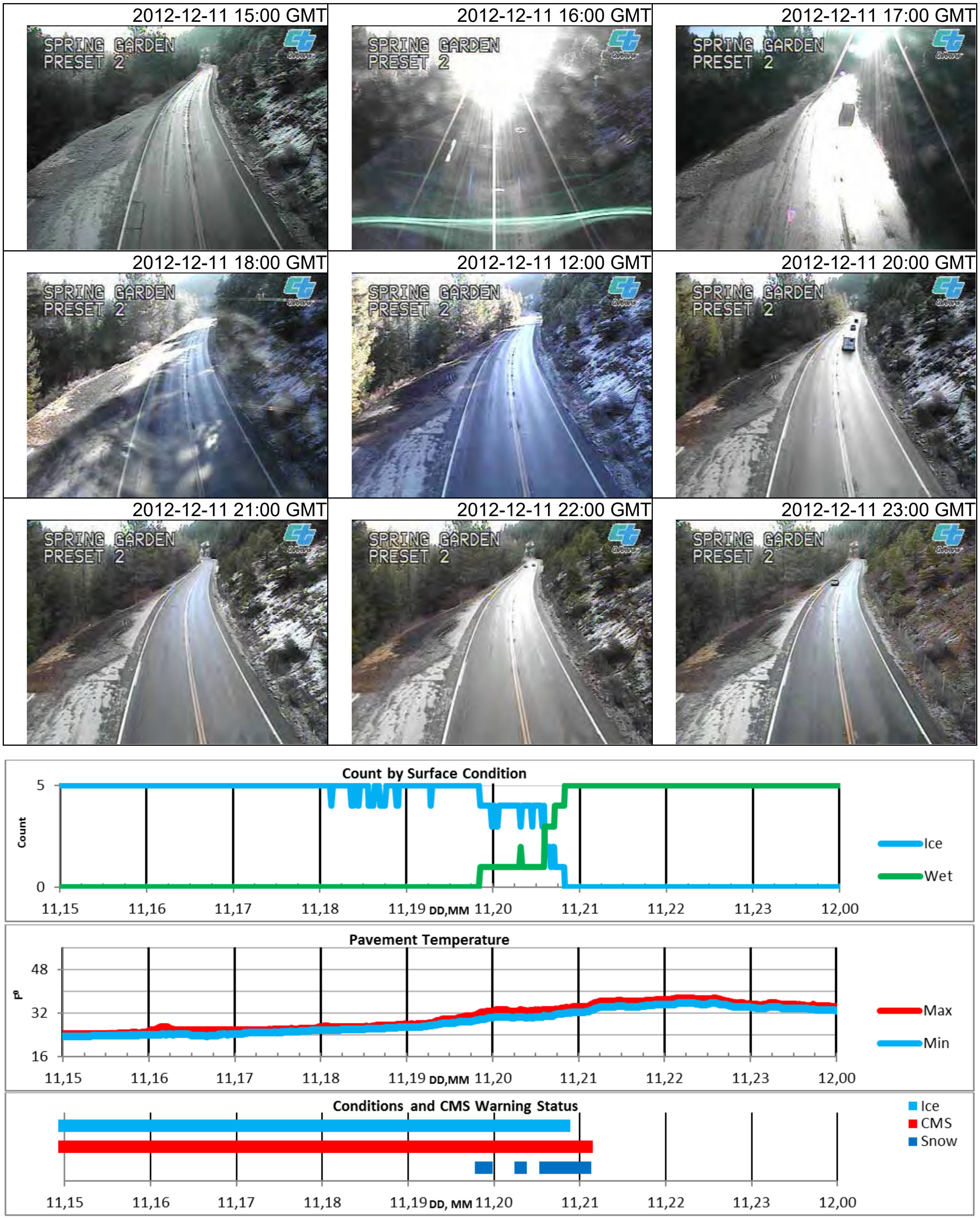

Figure 29: Conditions and Warning Status for 2012-12-11 GMT (pavement temperatures in °F, "Count" is the number of sensors reporting the given conditions)

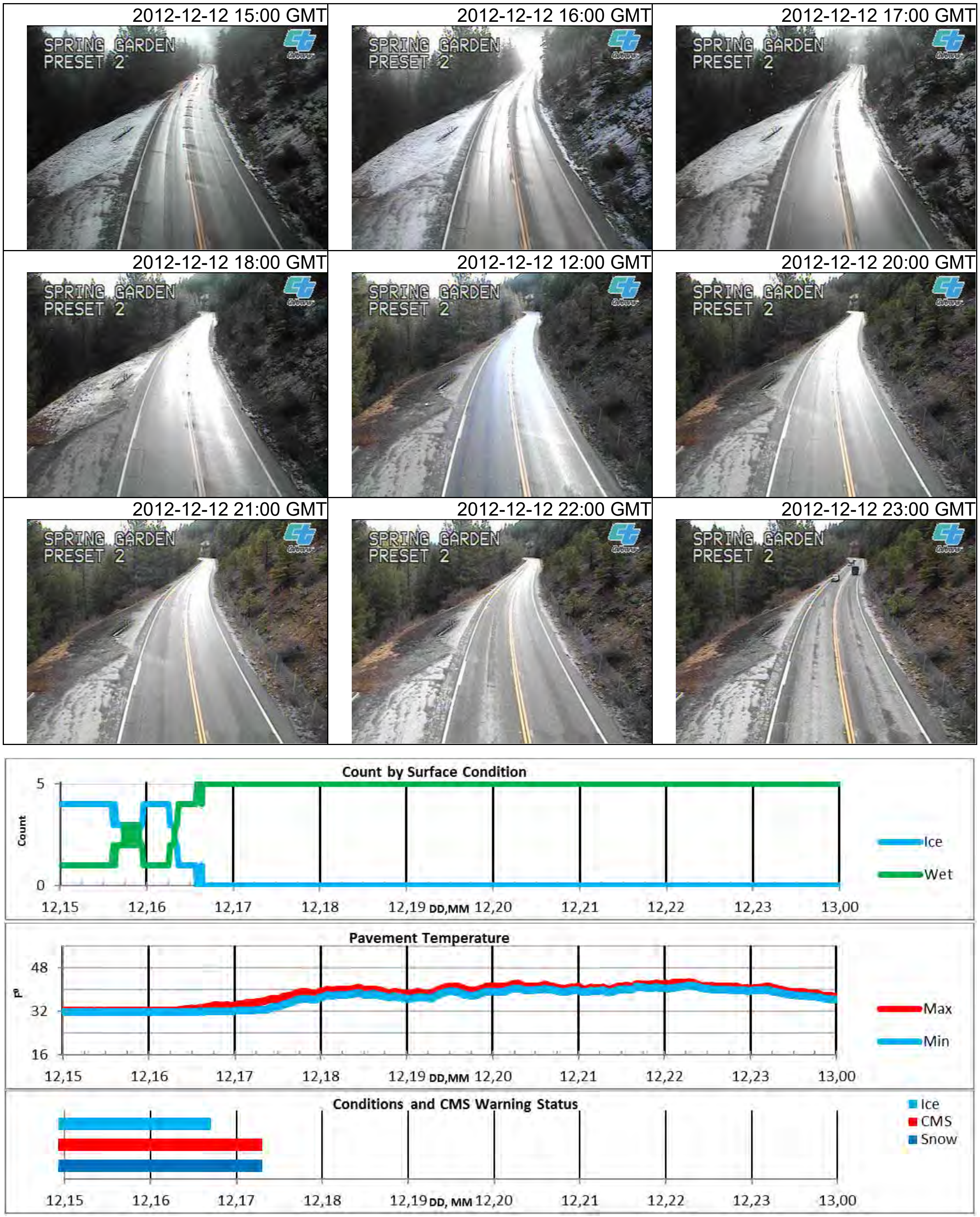

Figure 30: Conditions and Warning Status for 2012-12-12 GMT (pavement temperatures in ^{o}F, "Count" is the number of sensors reporting the given conditions)

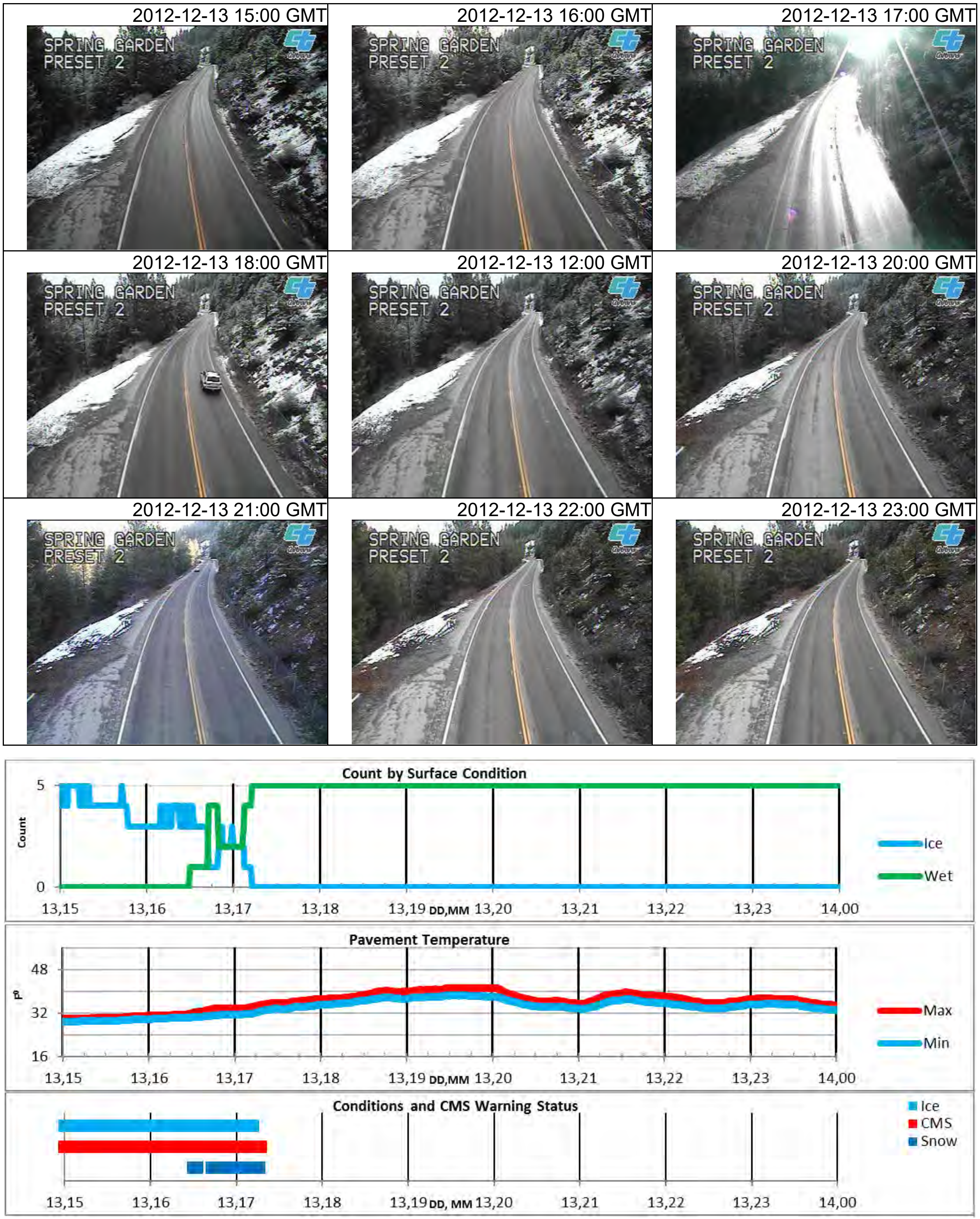

Figure 31: Conditions and Warning Status for 2012-12-13 GMT (pavement temperatures in °F, "Count" is the number of sensors reporting the given conditions)

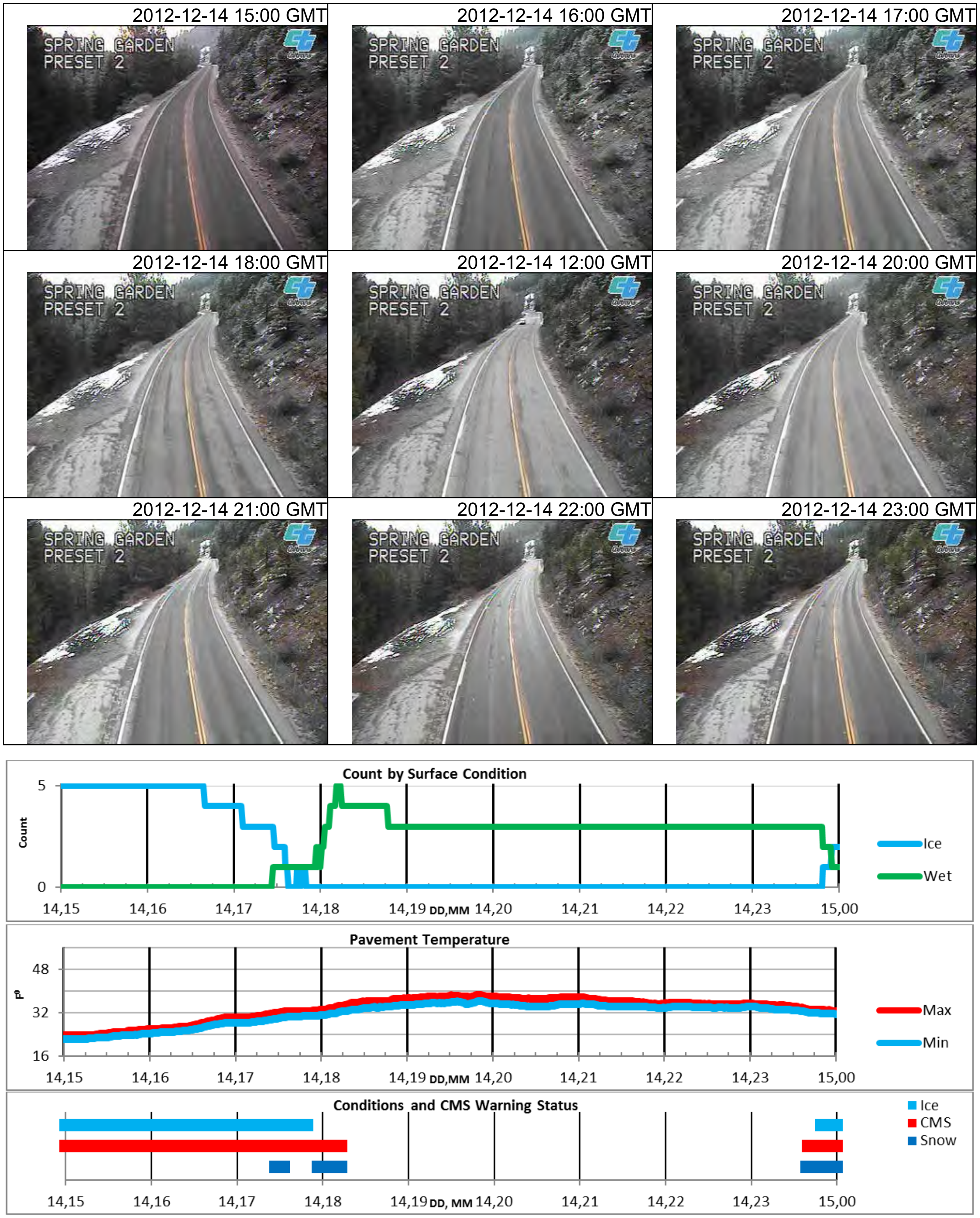

Figure 32: Conditions and Warning Status for 2012-12-14 GMT (pavement temperatures in ^{o}F, "Count" is the number of sensors reporting the given conditions)

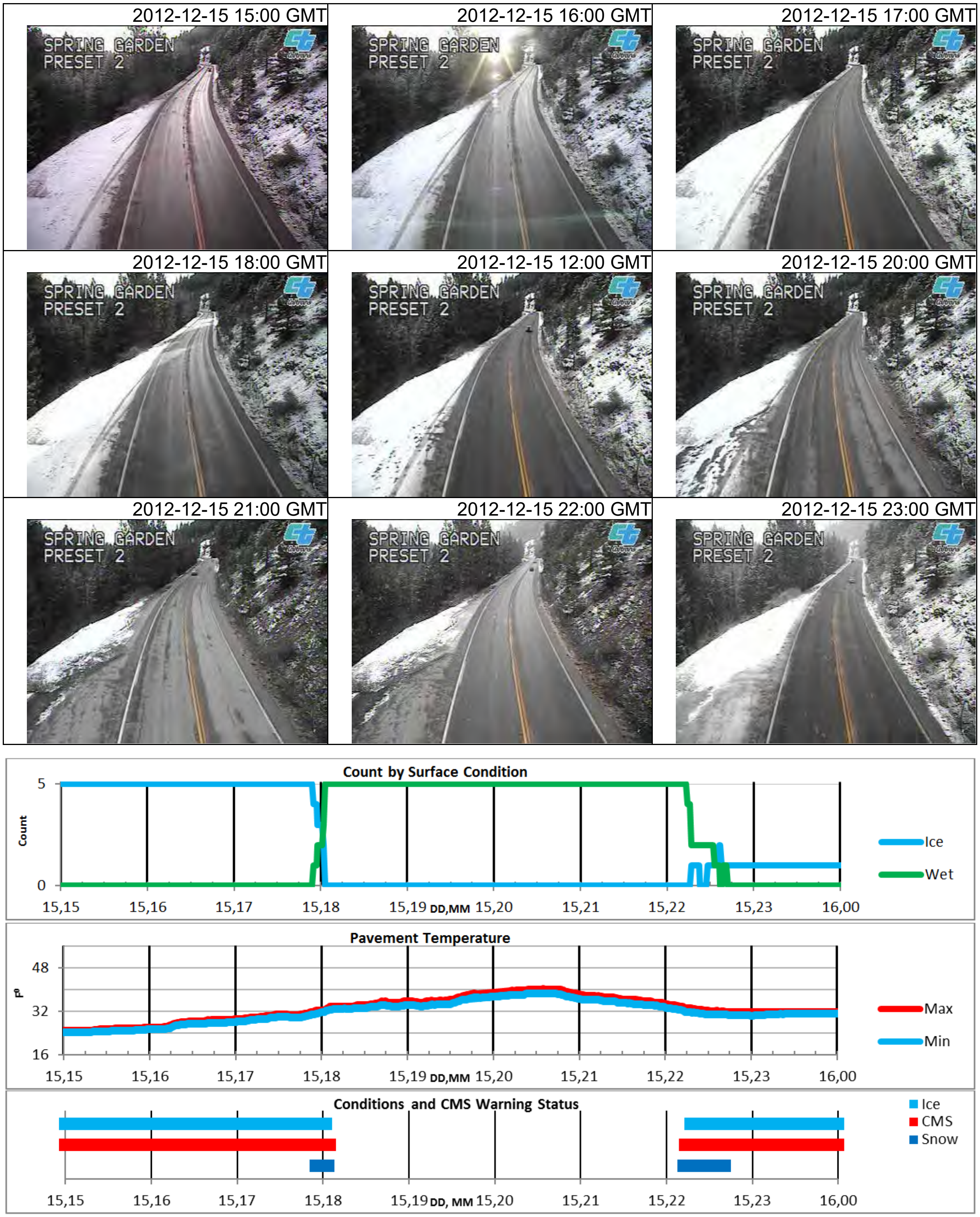

Figure 33: Conditions and Warning Status for 2012-12-15 GMT (pavement temperatures in ^{o}F, "Count" is the number of sensors reporting the given conditions)

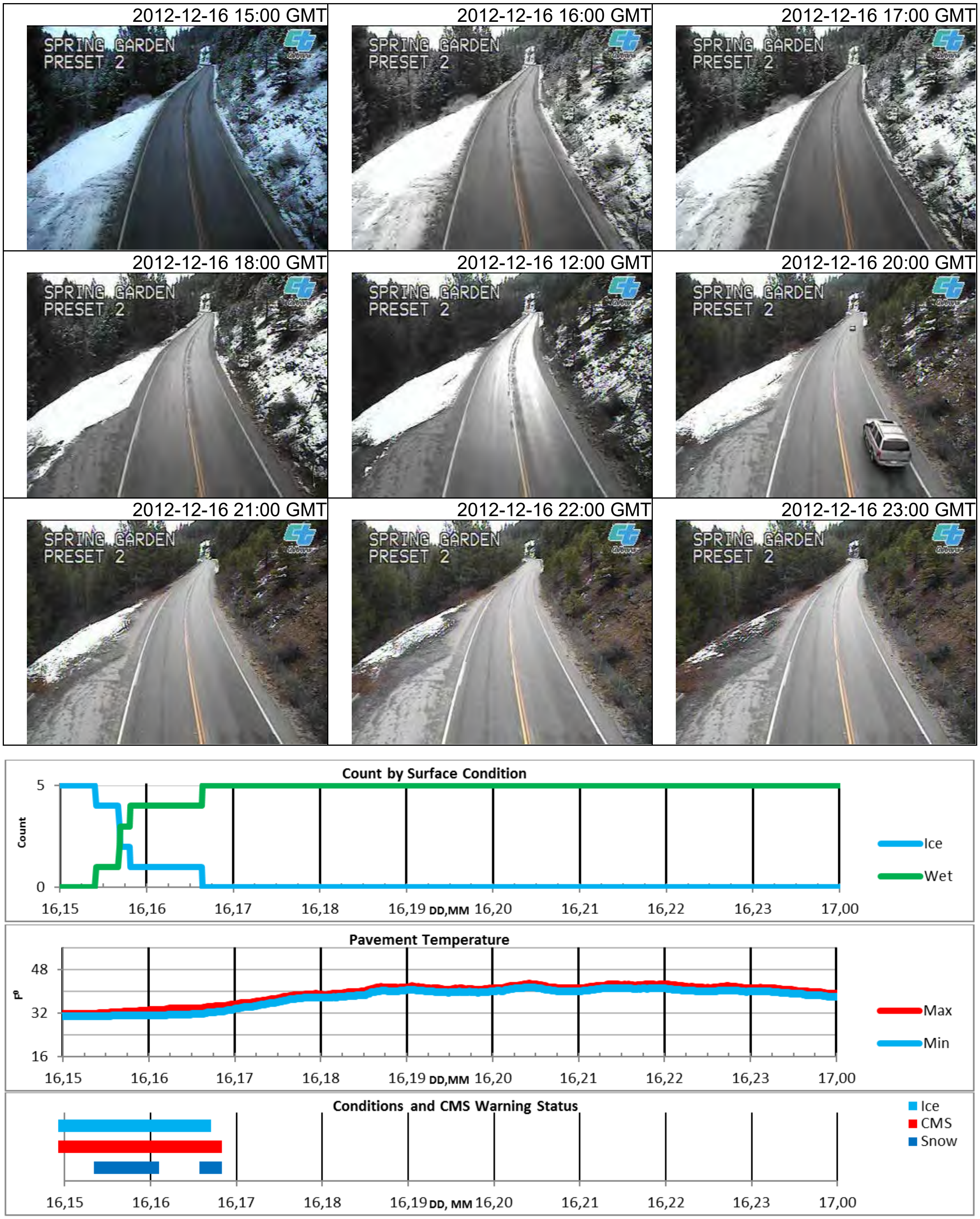

Figure 34: Conditions and Warning Status for 2012-12-16 GMT (pavement temperatures in ^{o}F, "Count" is the number of sensors reporting the given conditions)

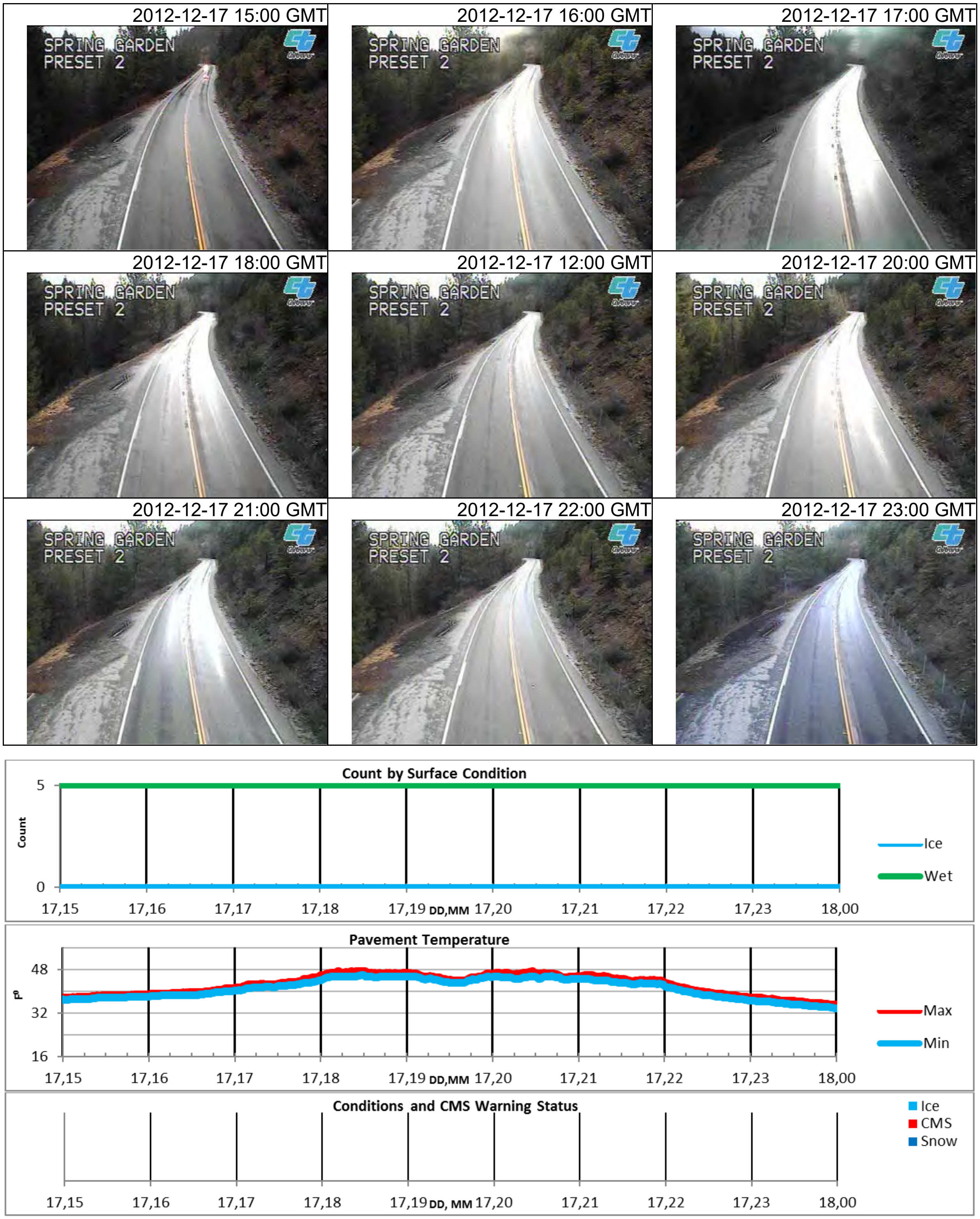

Figure 35: Conditions and Warning Status for 2012-12-17 GMT (pavement temperatures in ^{o}F, "Count" is the number of sensors reporting the given conditions)

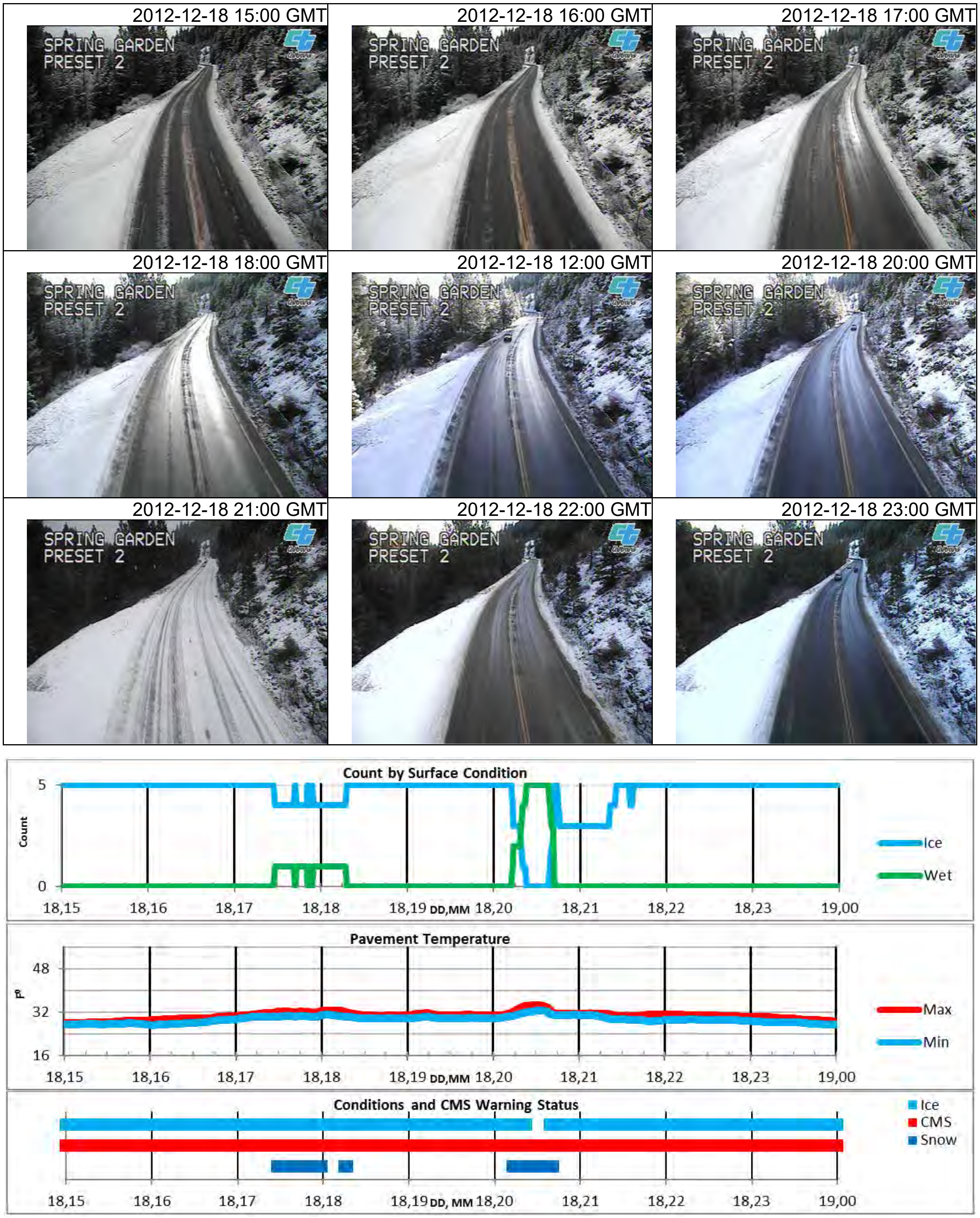

Figure 36: Conditions and Warning Status for 2012-12-18 GMT (pavement temperatures in °F, "Count" is the number of sensors reporting the given conditions)

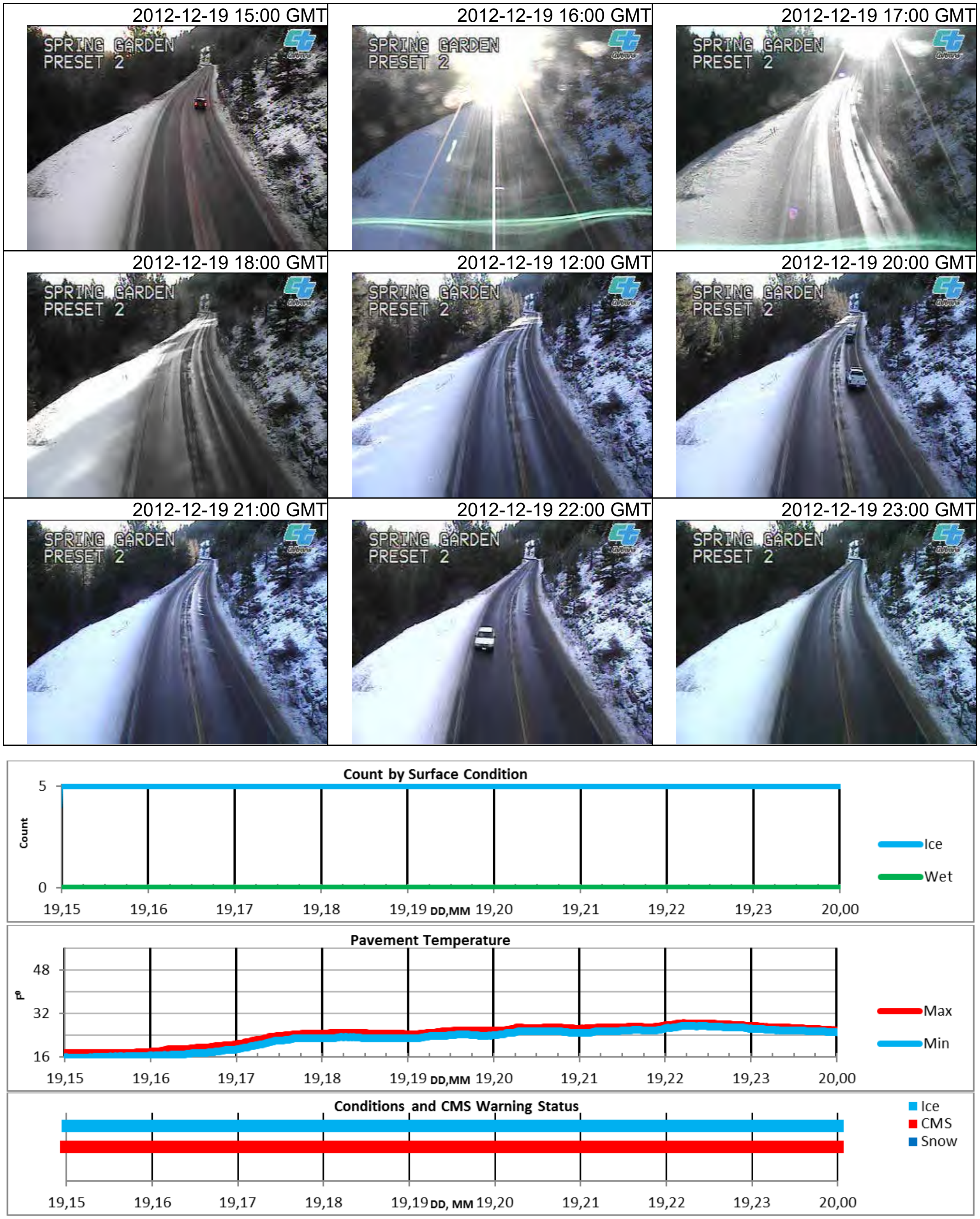

Figure 37: Conditions and Warning Status for 2012-12-19 GMT (pavement temperatures in ^{o}F, "Count" is the number of sensors reporting the given conditions)

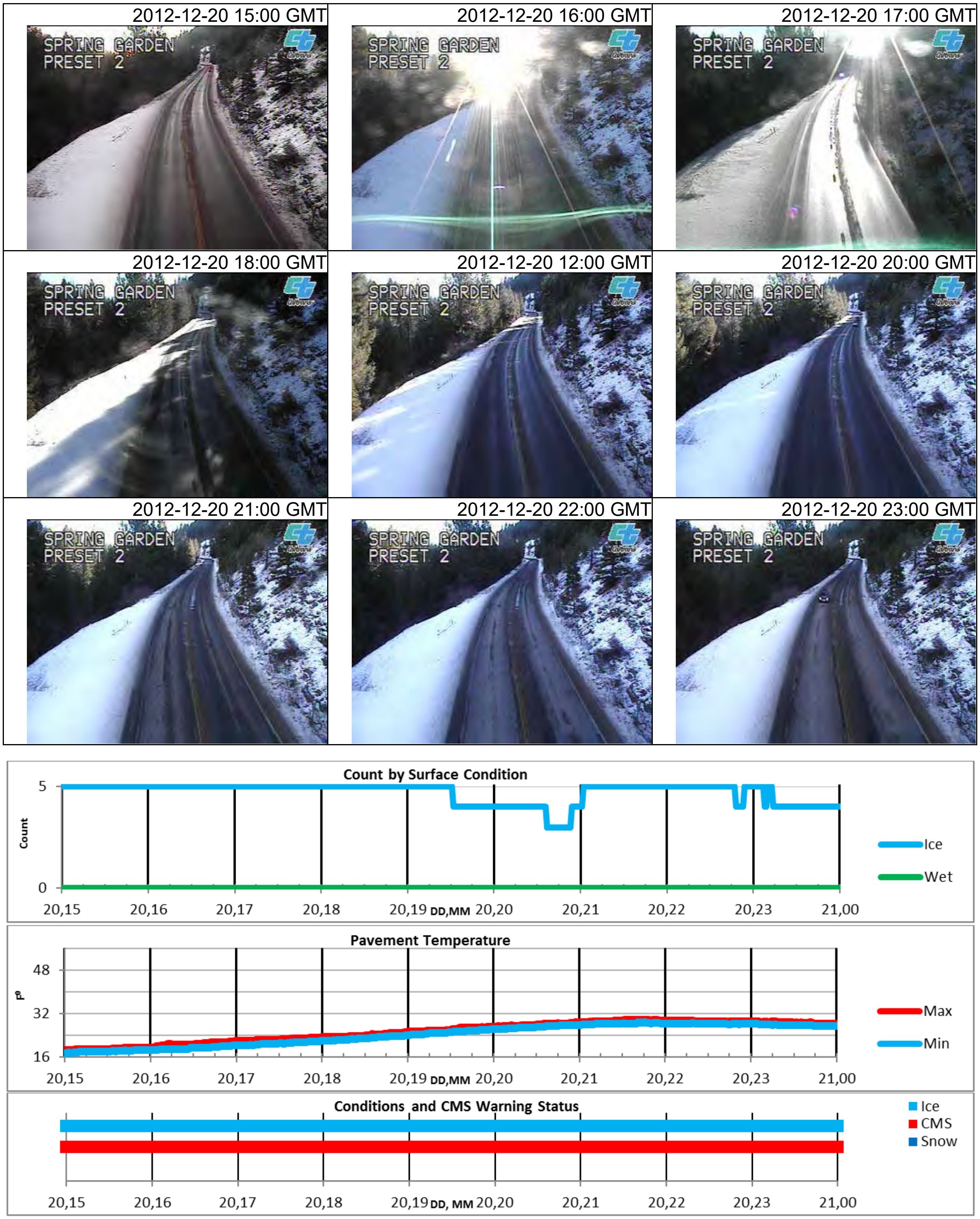

Figure 38: Conditions and Warning Status for 2012-12-20 GMT (pavement temperatures in °F, "Count" is the number of sensors reporting the given conditions)

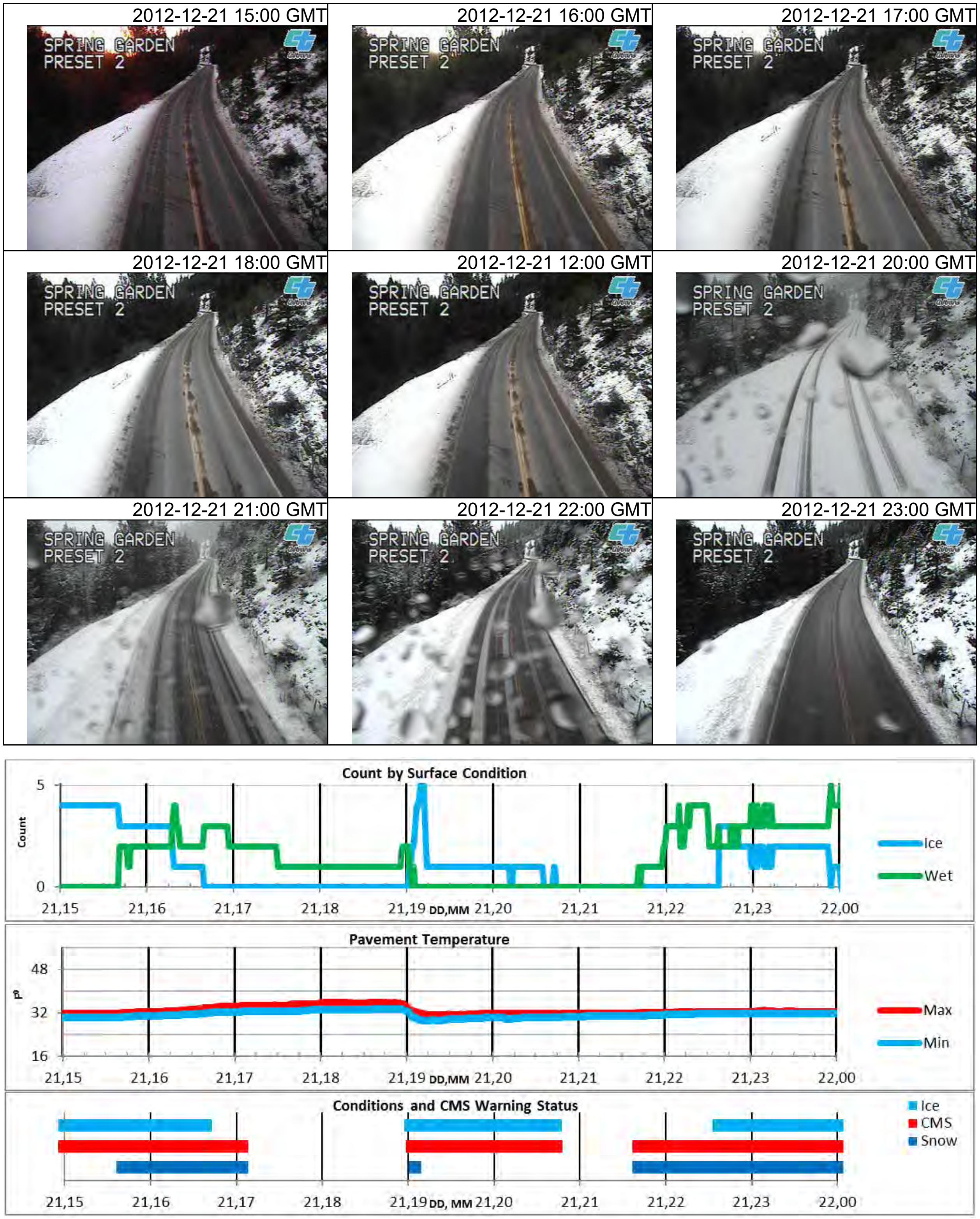

Figure 39: Conditions and Warning Status for 2012-12-21 GMT (pavement temperatures in °F, "Count" is the number of sensors reporting the given conditions)

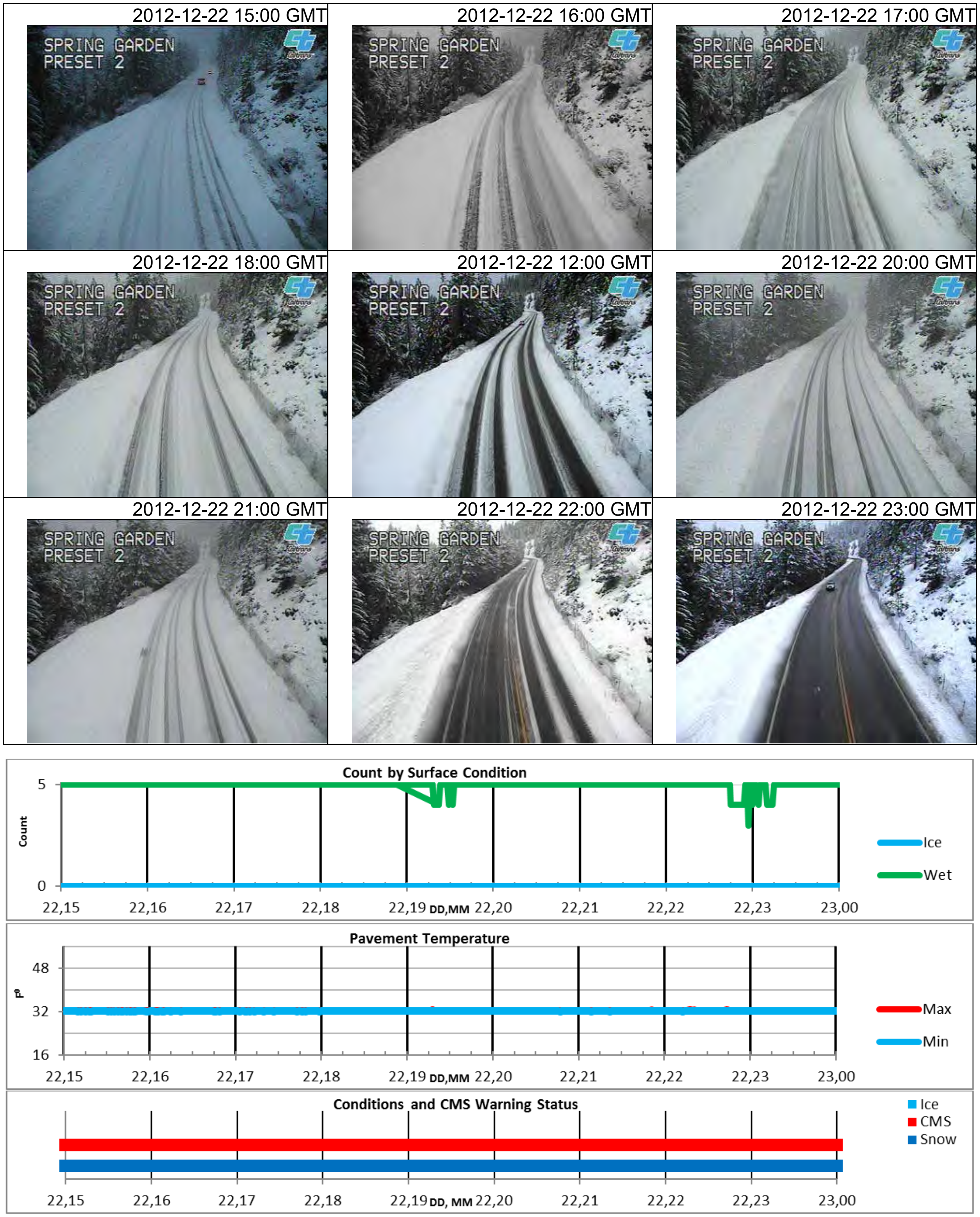

Figure 40: Conditions and Warning Status for 2012-12-22 GMT (pavement temperatures in °F, "Count" is the number of sensors reporting the given conditions)

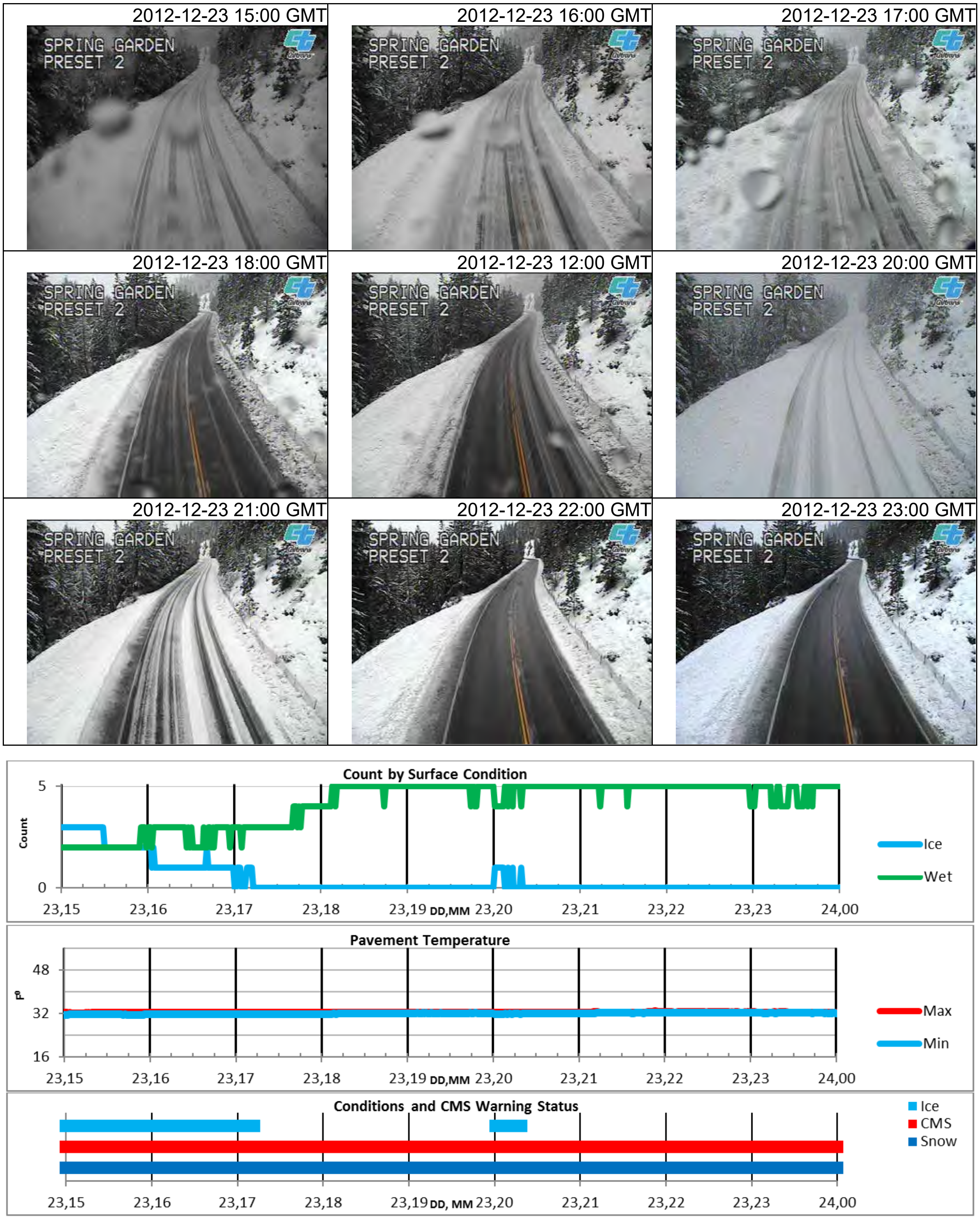

Figure 41: Conditions and Warning Status for 2012-12-23 GMT (pavement temperatures in ^{o}F, "Count" is the number of sensors reporting the given conditions)

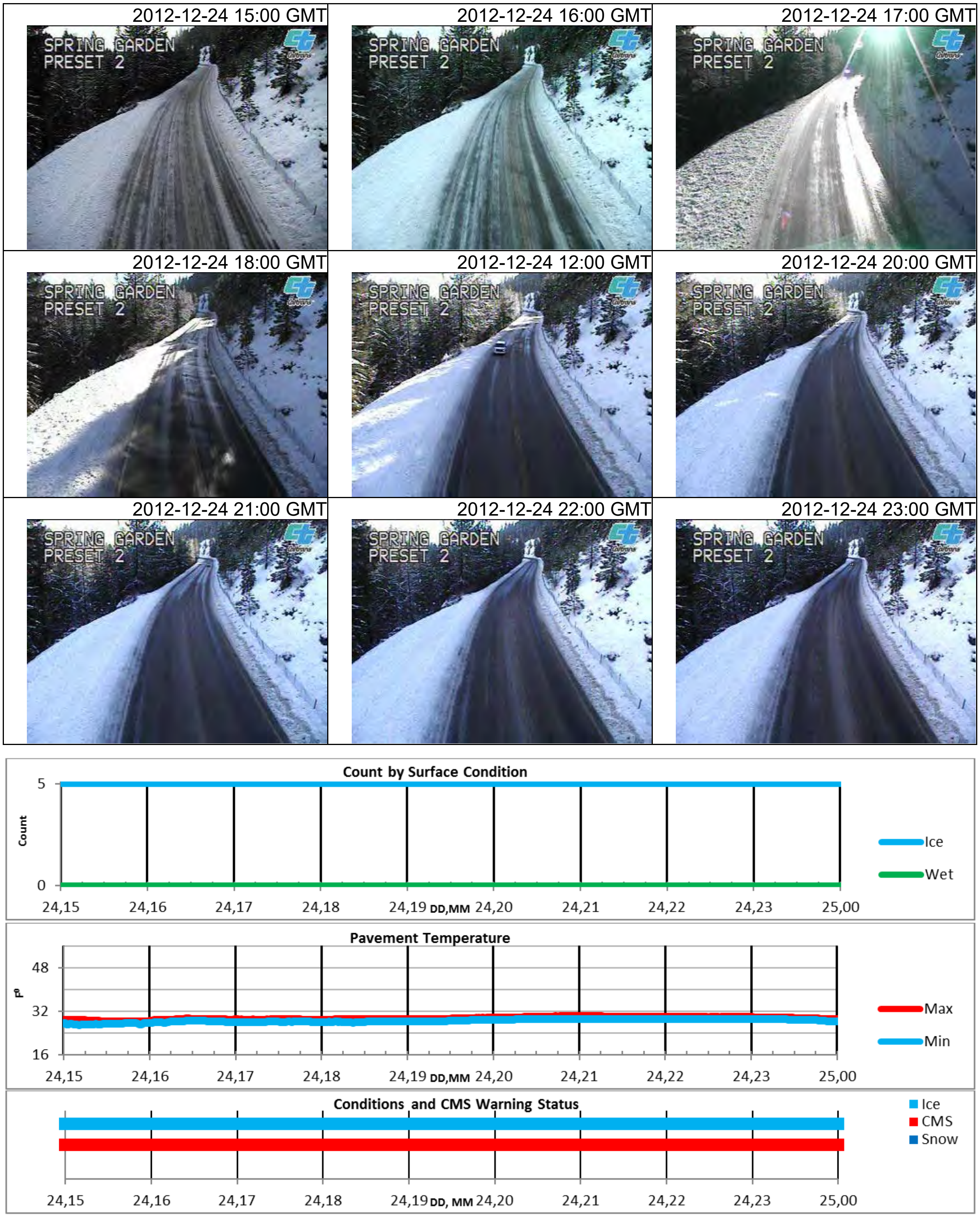

Figure 42: Conditions and Warning Status for 2012-12-24 GMT (pavement temperatures in °F, "Count" is the number of sensors reporting the given conditions)

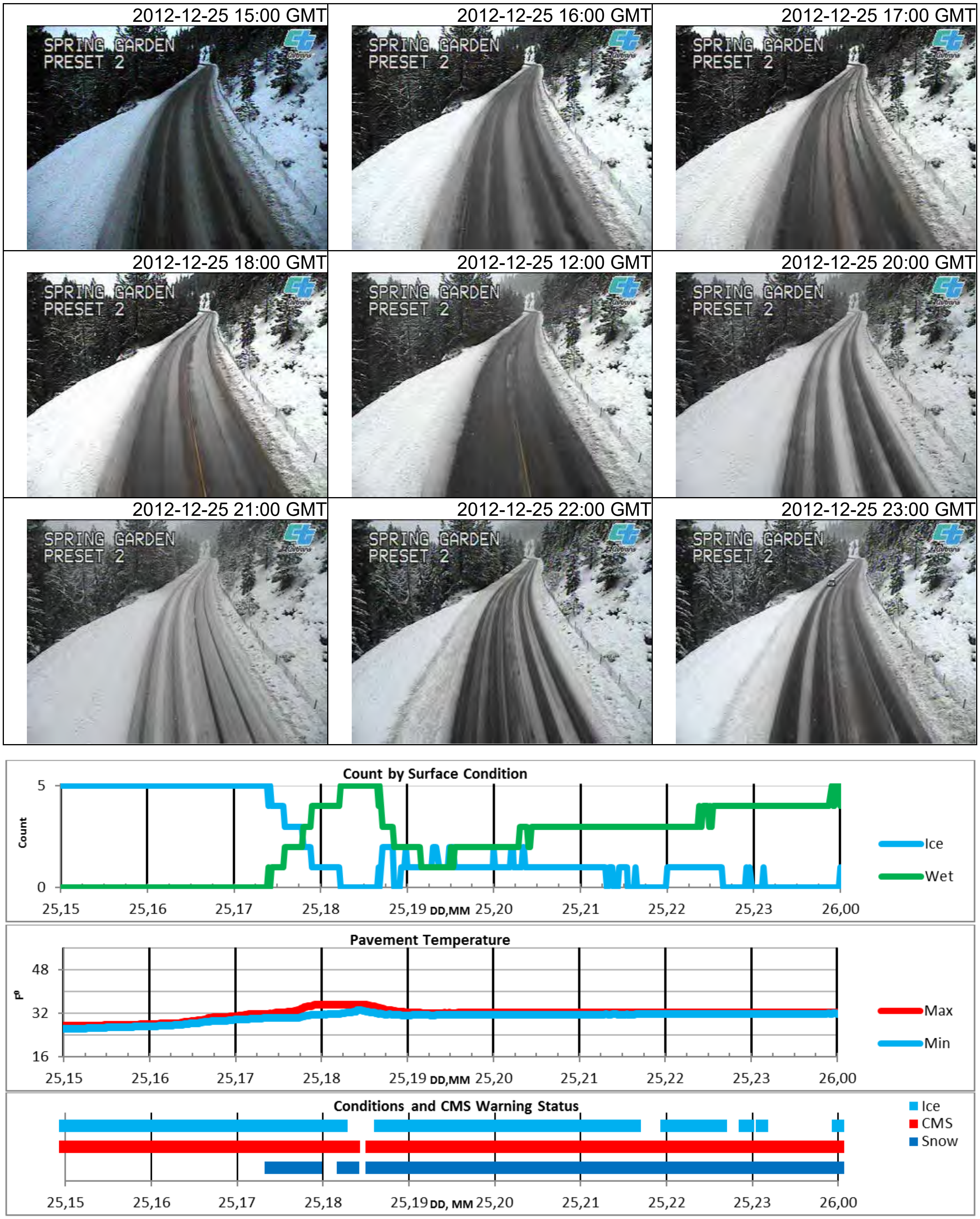

Figure 43: Conditions and Warning Status for 2012-12-25 GMT (pavement temperatures in °F, "Count" is the number of sensors reporting the given conditions)

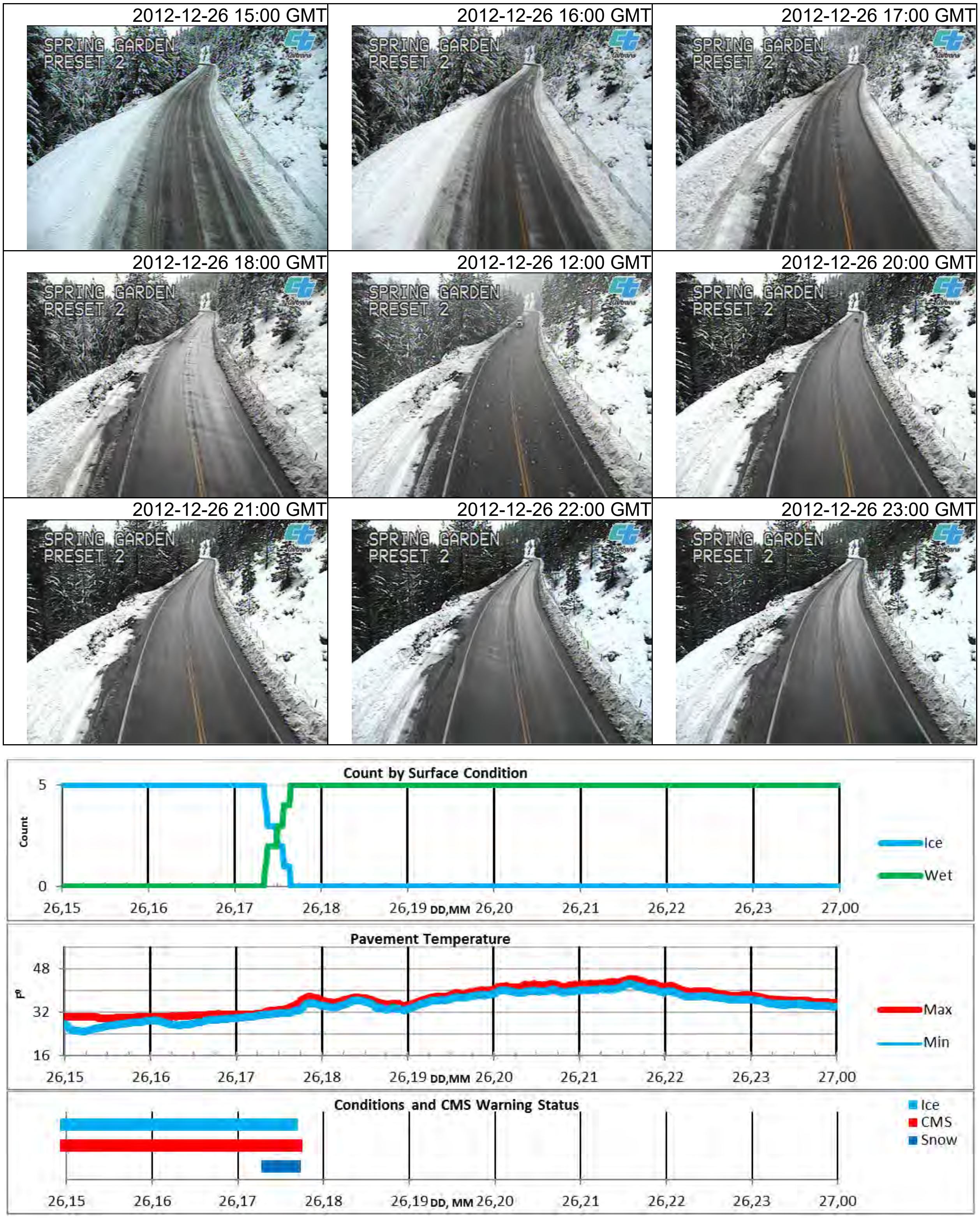

Figure 44: Conditions and Warning Status for 2012-12-26 GMT (pavement temperatures in °F, "Count" is the number of sensors reporting the given conditions)

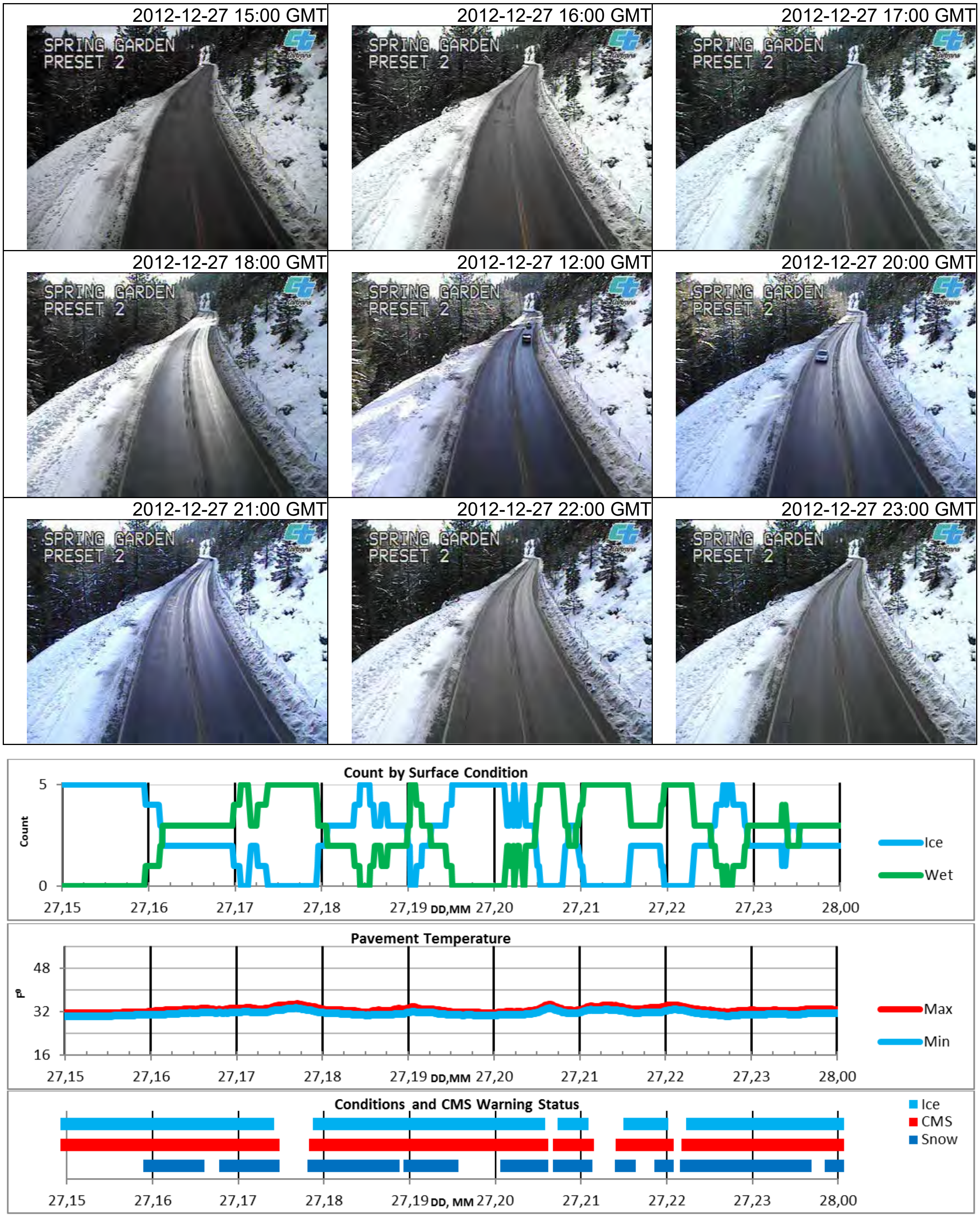

Figure 45: Conditions and Warning Status for 2012-12-27 GMT (pavement temperatures in °F, "Count" is the number of sensors reporting the given conditions)

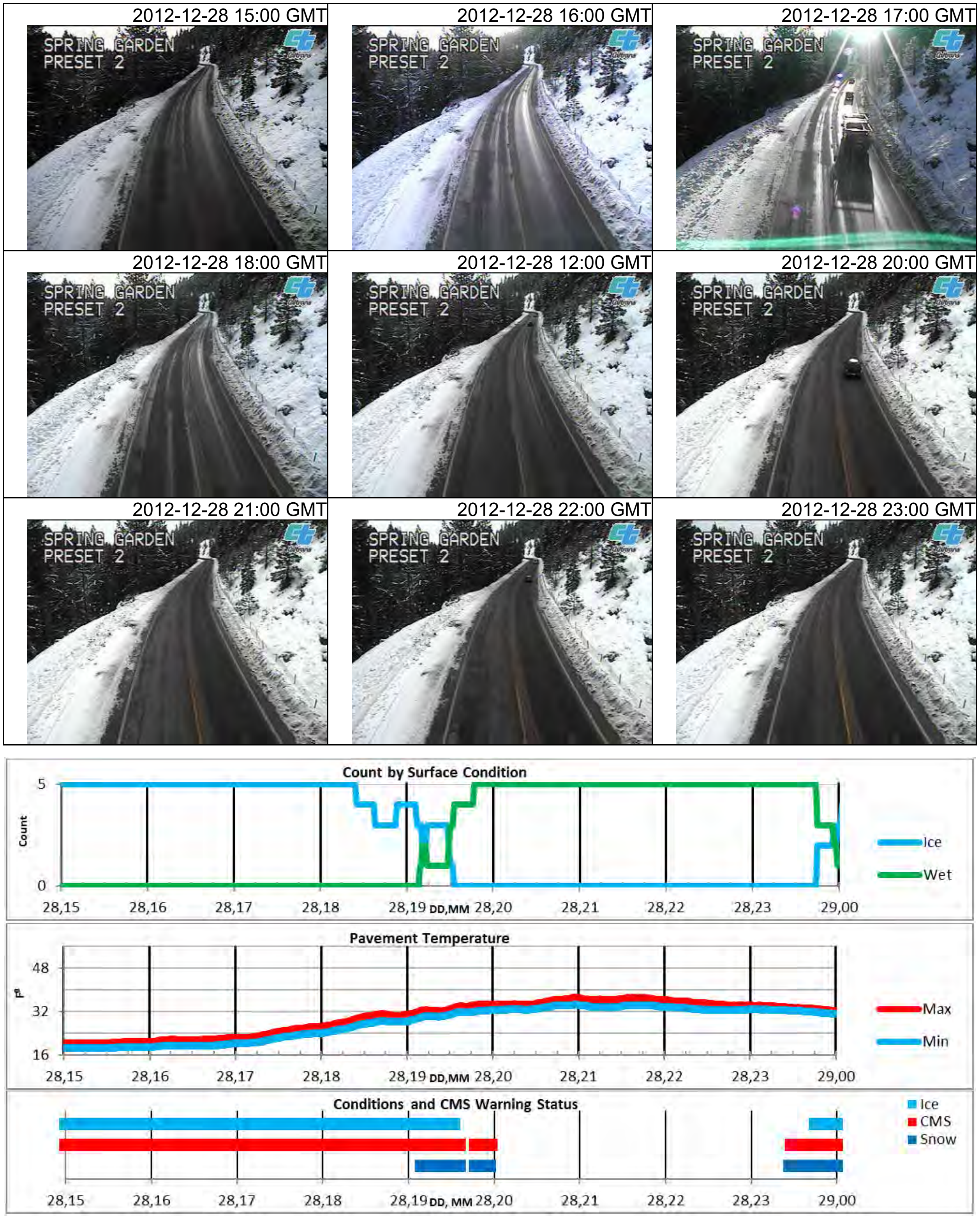

Figure 46: Conditions and Warning Status for 2012-12-28 GMT (pavement temperatures in °F, "Count" is the number of sensors reporting the given conditions)

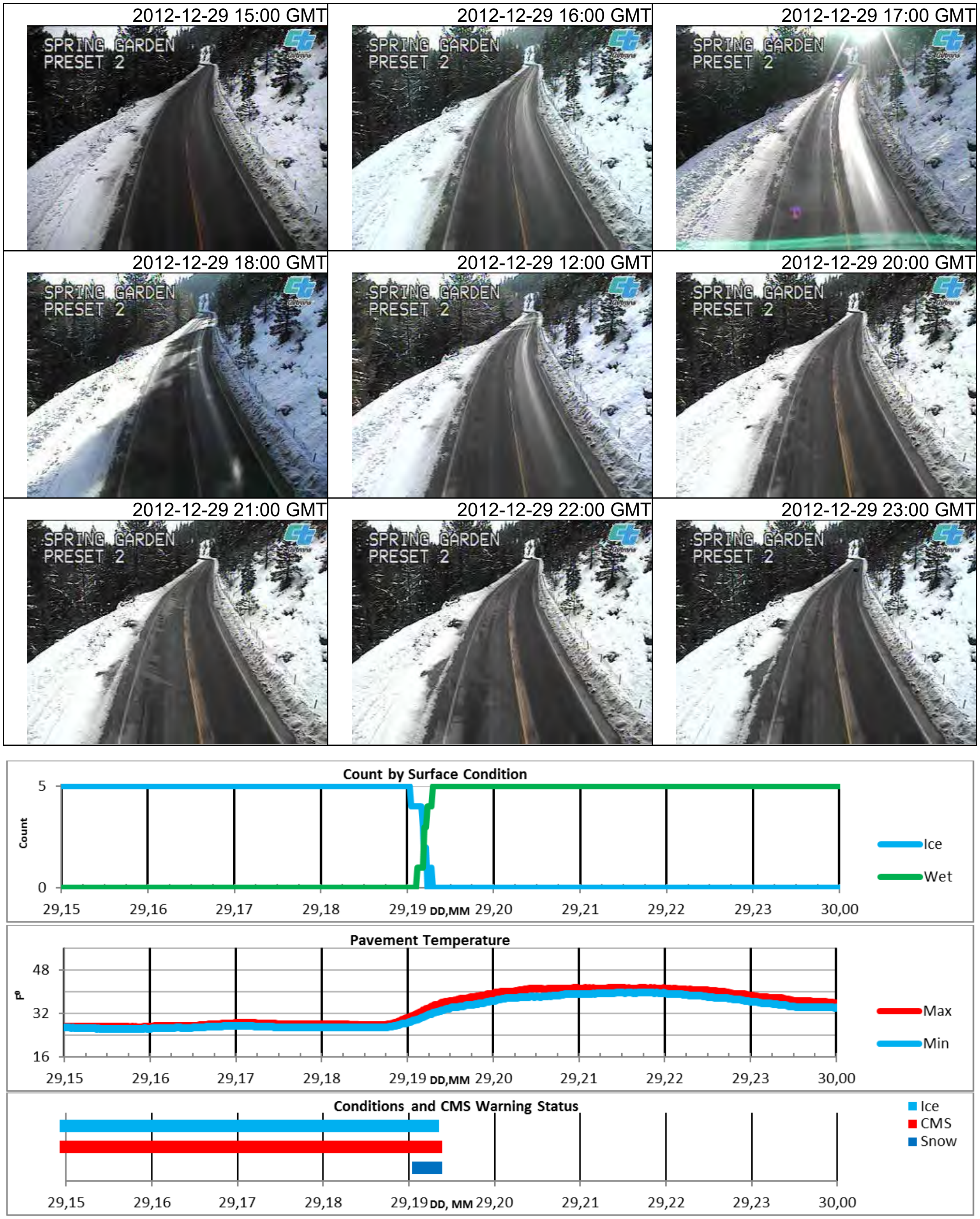

Figure 47: Conditions and Warning Status for 2012-12-29 GMT (pavement temperatures in ^{o}F, "Count" is the number of sensors reporting the given conditions)

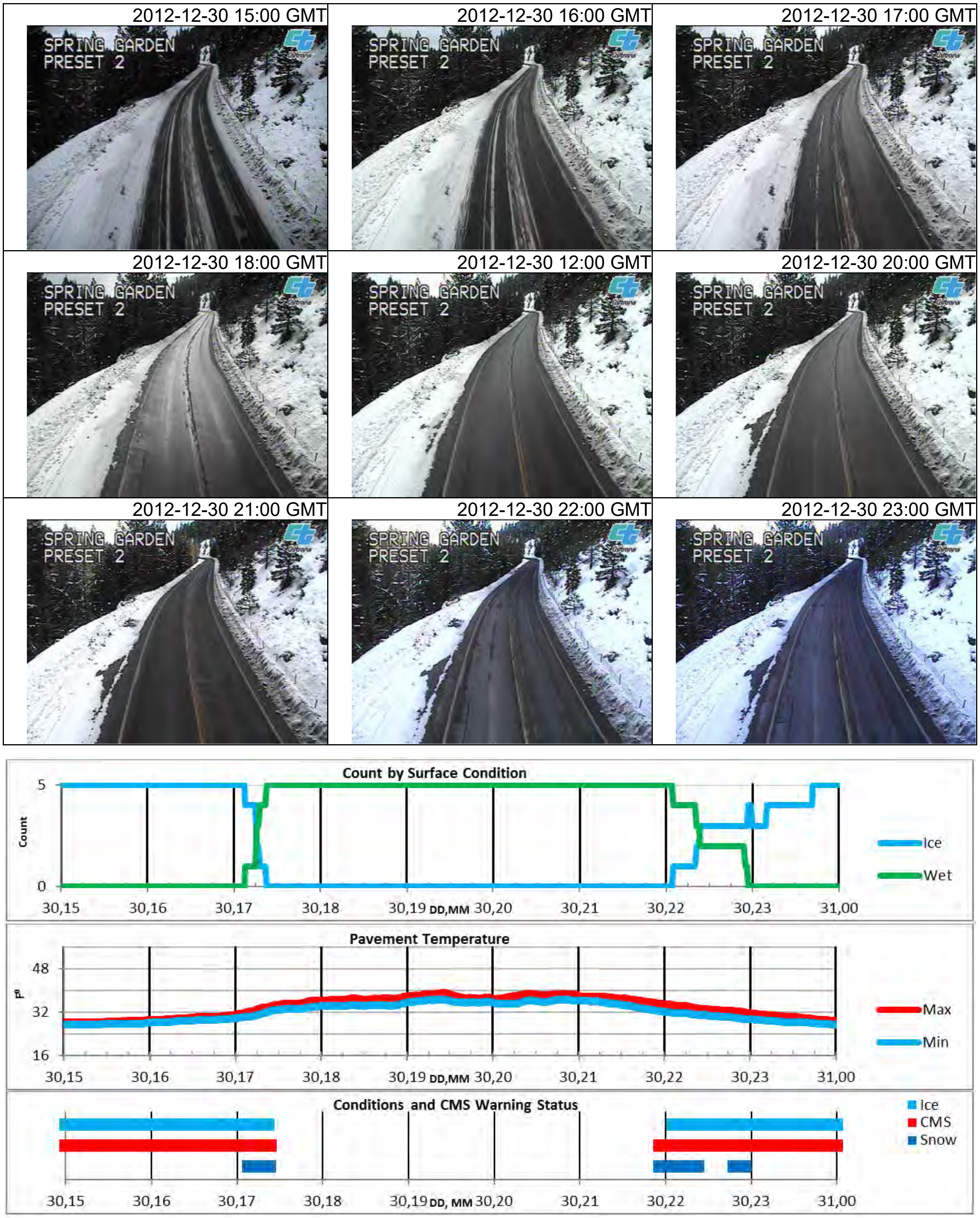

Figure 48: Conditions and Warning Status for 2012-12-30 GMT (pavement temperatures in ^{o}F, "Count" is the number of sensors reporting the given conditions)

7. CONCLUSION

A number of deliverables were produced during the course of the project effort, including:

- Final Report
- Quarterly Reports
- Review Summary and Recommendations
- System Development Summary
- System Management and Maintenance Guide
- System Testing Summary
- Long-term Maintenance and Management Plan
- Evaluation Summary

Some of these documents were consolidated, resulting in the following:

- Automated Safety Warning Controller System Review Summary and Recommendations
- Automated Safety Warning System Development Summary
- Automated Safety Warning Management and Maintenance Guide
- Automated Safety Warning Controller System Testing Plan and Summary and System Evaluation Plan and Summary

The Phase 1 ASWC has been running reliably and autonomously at Caltrans Spring Garden site for over three years has. The Phase 2 ASWC has been running in the Caltrans District 2 EE Lab for 3 months as of this writing and appears to be as reliable as the Phase 1 system. The Phase 2 system adds additional functionality including the ability for remote monitoring from a web browser. The next step would be to install the Phase 2 system at the pilot site in Spring Garden to allow for a more comprehensive evaluation of the SOCCS ASWC TMC interface. Further steps could include installation at additional sites with the implementation of additional alert scripts such as a wind warning. Protocol modules for various field elements other than RWIS and CMS have been written but not thoroughly tested due to time constraints and real world applications. In-lab and pilot testing of these additional field elements would be an additional next step.

8. REFERENCES

1. **Western Transportation Institute, February 2011**, *Automated Safety Warning Controller Phase 2 Review Summary and Recommendations*
2. **Western Transportation Institute, November 2011,** *Automated Safety Warning System Controller- Controller Message Protocol Definition Document*
3. **Western Transportation Institute, September 2007,** *Automated Safety Warning Controller System Concept and Requirements Specification*
4. **Western Transportation Institute, January 2013,** *Automated Safety Warning Controller System Development Summary*
5. **Western Transportation Institute, February 2013,** *Automated Safety Warning Controller System Testing Plan and Summary and System Evaluation Plan and Summary*

9. APPENDIX: TESTING PROCEDURES AND RESULTS FOR COMPACT FLASH CARDS

9.1. Procedure

Cards were tested with both FAT and ext2 file system formats. The ext2 file system on the disks was created using the mke2fs utility included on the MOXA Linux installation. The FAT file system was created on the disk using a Windows PC. Both cards using both file systems were stress tested by generating multiple large files using the command: *for i in 1 2 3 4 5 6 7; do head -n 500000 /dev/urandom > test$i.txt; done*, where *$i* represents the number of the iteration. The large files were filled with approximately 122 megabytes of random data. Testing was conducted on both the MOXA DA-661 and the UC-7420.

9.2. Results

SanDisk Ultra II/MOXA DA-661/FAT file system: The file system on the card mounted without error, and the large file creation test worked over seven iterations, creating files of a reasonably uniform 122 megabytes +/- 500 kilobytes. No errors were logged by the kernel.

SanDisk Ultra II/MOXA UC-7420/FAT file system: The file system on the card mounted without error, and the large file creation test worked over seven iterations, creating files of a reasonably uniform 122 megabytes +/- 500 kilobytes. No errors were logged by the kernel.

SanDisk Ultra II/MOXA DA-661/ext2 file system: The mke2fs utility provided by MOXA performed well, generating a new ext2 file system without noticeable errors. Likewise the large file creation test worked over seven iterations, creating files of a reasonably uniform 122 megabytes +/- 500 kilobytes. No errors were logged by the kernel.

SanDisk Ultra II/MOXA UC-7420/ext2 file system: The mke2fs utility provided by MOXA performed well, generating a new ext2 file system without noticeable errors. Likewise the large file creation test worked over seven iterations, creating files of a reasonably uniform 122 megabytes +/- 500 kilobytes. No errors were logged by the kernel.

Transcend TS4GCF150/MOXA DA-661/FAT file system: The file system on the card mounted without error, and the large file creation test worked over seven iterations, creating files of a reasonably uniform 122 megabytes +/- 500 kilobytes. No errors were logged by the kernel.

Transcend TS4GCF150/MOXA UC-7420/FAT file system: The card mounted without error, but the large file creation test failed on the first iteration. The device rebooted on the first trial, and the second trial failed with i/o errors. The following is partial dump of the kernel messages logged after the failed write:

```
<4>Directory sread (sector 0x7d8) failed
<4>end_request: I/O error, dev 03:01 (hda), sector 2008
<4>Directory sread (sector 0x7d8) failed
<4>end_request: I/O error, dev 03:01 (hda), sector 2008
<4>Directory sread (sector 0x7d8) failed
```

```
<4>end_request: I/O error, dev 03:01 (hda), sector 49
<4>bread in fat_access failed
<4>end_request: I/O error, dev 03:01 (hda), sector 49
<4>bread in fat_access failed
<4>end_request: I/O error, dev 03:01 (hda), sector 1
<4>FAT bread failed in fat_clusters_flush
<4>end_request: I/O error, dev 03:01 (hda), sector 45
<4>bread in fat_access failed
<4>Filesystem panic (dev 03:01).
<4>  File without EOF
<4>end_request: I/O error, dev 03:01 (hda), sector 49
<4>bread in fat_access failed
```

Transcend TS4GCF150/MOXA DA-661/ext2 file system: The mke2fs utility provided by MOXA performed with limited and intermittent success. Approximately one in three tries would successfully create and validate an ext2 file system on the card. Failed attempts resulted in an unexpected reboot of the system. Upon a successful execution of mke2fs the card file system would mount without problem. Attempts to write a large file would fail during the second or third iteration with i/o errors. Following is a partial dump of the kernel messages logged after a failed large file write:

```
EXT2-fs error (device hda1): read_block_bitmap: Cannot read block
bitmap - block_group = 5, block_bitmap = 164080
end_request: I/O error, dev hda, sector 3523055
end_request: I/O error, dev hda, sector 3523055
end_request: I/O error, dev hda, sector 1999
end_request: I/O error, dev hda, sector 63
Buffer I/O error on device hda1, logical block 0
lost page write due to I/O error on hda1
EXT2-fs error (device hda1): ext2_get_inode: unable to read inode
block - inode=2, block=242
end_request: I/O error, dev hda, sector 1312735
end_request: I/O error, dev hda, sector 63
Buffer I/O error on device hda1, logical block 0
lost page write due to I/O error on hda1
EXT2-fs error (device hda1): ext2_get_inode: unable to read inode
block - inode=40879, block=164084
end_request: I/O error, dev hda, sector 4143
end_request: I/O error, dev hda, sector 1312727
end_request: I/O error, dev hda, sector 63
EXT2-fs error (device hda1): ext2_get_inode: unable to read inode
block - inode=40840, block=164083
end_request: I/O error, dev hda, sector 3407951
end_request: I/O error, dev hda, sector 63
EXT2-fs error (device hda1): ext2_get_inode: unable to read inode
block - inode=106095, block=425986
```

```
end_request: I/O error, dev hda, sector 1312735
end_request: I/O error, dev hda, sector 63
EXT2-fs error (device hda1): ext2_get_inode: unable to read inode
block - inode=40871, block=164084
end_request: I/O error, dev hda, sector 71
```

Transcend TS4GCF150/MOXA UC-7420/ext2 file system: The mke2fs utility provided by MOXA performed with limited and intermittent success. Approximately one in three tries would successfully create and validate an ext2 file system on the card. Failed attempts resulted in an unexpected reboot of the system. Upon a successful execution of mke2fs the card file system would mount without problem. Attempts to write a large file caused an unexpected reboot in two out of three trials, the first with 32.9 megabytes written to the 3rd file, the second with 102.3 megabytes written to the second file. The second of three trials resulted in i/o errors; the following is a sample of the kernel messages logged during this test:

```
<4>end_request: I/O error, dev 03:01 (hda), sector 0
<2>EXT2-fs error (device ide0(3,1)): ext2_new_block: Free blocks count
corrupted for block group 4
<4>end_request: I/O error, dev 03:01 (hda), sector 0
<2>EXT2-fs error (device ide0(3,1)): ext2_new_block: Free blocks count
corrupted for block group 4
<4>end_request: I/O error, dev 03:01 (hda), sector 0
<2>EXT2-fs error (device ide0(3,1)): ext2_new_block: Free blocks count
corrupted for block group 4
<4>end_request: I/O error, dev 03:01 (hda), sector 0
<2>EXT2-fs error (device ide0(3,1)): ext2_new_block: Free blocks count
corrupted for block group 4
<4>end_request: I/O error, dev 03:01 (hda), sector 0
<2>EXT2-fs error (device ide0(3,1)): ext2_new_block: Free blocks count
corrupted for block group 4
<4>end_request: I/O error, dev 03:01 (hda), sector 524320
<4>end_request: I/O error, dev 03:01 (hda), sector 0
<2>EXT2-fs error (device ide0(3,1)): ext2_write_inode: unable to read
inode block - inode=32648, block=65540
<4>end_request: I/O error, dev 03:01 (hda), sector 4112
<4>end_request: I/O error, dev 03:01 (hda), sector 4112
<4>end_request: I/O error, dev 03:01 (hda), sector 32
<4>end_request: I/O error, dev 03:01 (hda), sector 0
<2>EXT2-fs error (device ide0(3,1)): ext2_write_inode: unable to read
inode block - inode=2, block=4
<4>end_request: I/O error, dev 03:01 (hda), sector 4112
<4>end_request: I/O error, dev 03:01 (hda), sector 4112
<4>end_request: I/O error, dev 03:01 (hda), sector 32
<4>end_request: I/O error, dev 03:01 (hda), sector 0
```

10. APPENDIX: ANALYSIS OF SYSTEM CLOCK DRIFT AND ADJUSTMENT ON ASWC OPERATION

10.1. Background of Clock Drift Problem

In lab testing and experimentation, it has been found that the Moxa DA-661, as shipped from the factory, has a significant issue with the system clock losing time; clock drift as great as 35 seconds/hour have been observed. The release notes for the latest version of DA-661 firmware, 1.6 build 10070920, include the change "Adjust system time precision". This document outlines procedures and results for testing clock drift on this latest firmware build.

10.2. Procedure

At the start of each test, the hardware and system clocks were manually set by issuing the command `date -s` *`mmddHHMMyyyy`*`; hwclock -w` when the external time source turned over to 0 seconds. At the conclusion of each test the time was evaluated by issuing the command `date; hwclock` when the external time source turned over to 0 seconds so that the amount of time taken to record and compare the clock times didn't affect the results. The external time source is automatically synchronized with NIST official time. In setting the time and evaluating the amount of clock drift at the end of each test there is a measured combined network delay of approximately 150 milliseconds. There is also a human reaction time delay in pressing the enter key, which has not been measured.

Test 1:
The initial test of the new build of firmware was straightforward, the device was upgraded to the new firmware, the hardware and system clocks were set to the current time, and the device was allowed to sit idle for 24 hours.

Test 2:
The second test was performed for 24 hours, evaluating clock drift when the system was busy primarily in user-space. The user-space load was generated using gzip on a 12.3 MB file of random data. Completion of a single iteration took an average of 39.3 seconds, 36.3 of which was user time and 2.8 was system time. Iterations were done in an infinite loop, commenced at startup of the device, with a 10 second rest in between. The test was initiated by setting the hardware and system clocks to the current time and rebooting the device to start the testing loop. The actual testing procedure was constructed by adding the following line of code to */etc/rc.d/rc.local*:

```
while true; do gzip -c datafile > /dev/null; sleep 10; done &
```

Test 3:
This test was performed for 24 hours, evaluating clock drift when the system was busy primarily in kernel-space. The kernel-space load was generated using find, cat, and the virtual file */dev/null*. The load consisted of using find to name every file on the mounted filesystems, reading every byte from each file, and forwarding those bytes to */dev/null*. Completion of a single iteration took an average of 10.97 seconds, 1.88 of which was user time and 9.08 was system time. The actual testing procedure was constructed by adding the following line of code to */etc/rc.d/rc.local*:

```
while true; do for i in {bin,etc,home,lib,mnt,sbin,tmp,usr,var};
```

```
do for j in $(find /$i -type f); do cat $j > /dev/null; done;
done; done&
```

Test 4:
This test was performed for 24 hours, evaluating clock drift under the typical load of the Automated Warning Safety Controller software. The test consisted entirely of running the ASWC software on an otherwise idle device.

10.3. Results

Firmware	Test 1 clock drift	Test 2 clock drift	Test 3 clock drift	Test 4 clock drift
1.5 build 08040117	-863 seconds	-865 seconds	-868 seconds	-866 seconds
1.6 build 10070920	-1 second	-1 second	-1 second	-0 seconds

Test 1:
The idle device test showed a system clock drift of -1 second, and a hardware clock drift of 0 seconds. The same test performed on firmware 1.5 build 08040117 resulted in a system clock drift of -863 seconds and a hardware clock drift of 0 seconds.

Test 2:
The user-space-busy test showed a system clock drift of -1 second, and a hardware clock drift of 0 seconds. The same test with firmware 1.5 build 08040117 showed a system clock drift of -865 seconds and a hardware clock drift of 0 seconds.

Test 3:
The kernel-space-busy test showed a system clock drift of -1 second, and a hardware clock drift of 0 seconds. The same test with firmware 1.5 build 08040117 showed a system clock drift of -868 seconds and a hardware clock drift of 0 seconds.

Test 4:
The test using a typical load of ASWC software showed a system clock drift of 0 seconds, and a hardware clock drift of 0 seconds. The same test with firmware 1.5 build 08040117 showed a system clock drift of -866 seconds and a hardware clock drift of 0 seconds.

The new firmware version greatly improved issues with the system clock on the DA-661 hardware. The system clock was shown to lose approximately 1 second per day, and the hardware clock did not lose any appreciable amount of time during the test period. It would be possible to regularly reset the system clock from the hardware clock, correcting the approximate 1 second per day that is lost by the system clock; it would also be possible for the software to read directly from the hardware clock, bypassing the system clock altogether. Such a change to the software would require a moderate time investment: every instance of time-related library functions would need to be replaced with a custom time function that queries the hardware clock and converts it to the expected type.

10.4. Implications

A regular adjustment of the system clock may bear some implications affecting the normal operation of the ASWC software. Along with the analysis measuring clock drift on the Moxa device, a code audit was conducted to find any areas of the software that may be affected by adjustment of the system clock during operation. Several areas of concern were found during the code audit, and severity was proportional to the amount of time the clock was adjusted.

Data file archiving: To keep data files small, an archiving process is implemented in the ASWC software. Data files are archived when a configurable number of readings is reached. When this happens, a duplicate of the current data file is made, the current data file is erased, and, for data persistence, every data record within a configurable age is saved in the new data file. A clock adjustment at any time within that age period before an archiving operation would affect the number of records retained; a large clock adjustment just prior to an archiving operation would even leave the persistent data empty.

Event logging: All system events are logged and time stamped. A clock adjustment during ASWC operation would affect the timestamps, producing either a gap or an overlap. While not affecting the software's functionality, this can lead to misunderstanding and confusion while auditing system log files.

Outgoing field element message queue: Some outgoing field element types maintain a queue of messages to be applied to the field element based on a priority field. All messages in the queue have an associated expiration age; messages are removed after they reach this age. A clock adjustment would affect the actual lifetime of any message in the queue at the time of the clock adjustment, either shortening or extending it.

Retrieving historical sensor data: Some alert script algorithms require access, not only to the current value of a specific sensor, but also previous readings over a period of time. A clock adjustment would affect the subjective age of sensor readings, either extending or collapsing the window of readings that were requested. This has the possibility of skewing averages, maximums, or minimums calculated over time.

Obviously, a clock adjustment of a few seconds has little impact in any of these areas, but an adjustment of an hour could have disastrous results. Upgrading all DA-661 hardware to the latest firmware build, regular synchronization with the hardware clock, and administrative verification of both clocks at least monthly should alleviate any issues that may arise from clock drift on the Moxa DA-661 hardware.

11. APPENDIX: SUMMARY OF ALTERNATIVE CONTROLLER DEVICES

The intent of this document is to show potential alternatives to the Moxa embedded computers that have been used on the Caltrans Automated Safety Warning System Controller project. Several problems with the Moxa devices have necessitated a search for alternatives. It is unclear whether an alternative platform will be selected and tested within the current phase of the project. However, it is necessary to know that there are viable alternatives in the event that a decision is made to discontinue use of the Moxa devices.

This list is by no means exhaustive, but does demonstrate that there are alternative devices on the market, including advanced transportation controllers (ATCs) that are specifically designed for transportation applications. It is unclear at this point how flexible ATCs are in terms of whether they could accommodate and application like ASWC. They do appear promising though since many are now based on a Linux platform. With respect to features supported by the ASWC software, none of the general purpose devices compare favorably to the Moxa DA-661. We've included one example of an LCD panel computer which, when coupled with a 19" rack adapter may be a desirable route to investigate.

General Requirements

General device requirements are:

- Can run Linux and Python
- Built-in LCD interface with buttons
- Removable data storage, 4 GB or greater
- 1U rack-mount
- Fanless
- At least one Ethernet port
- Extended operating temperature, at least -20°C to 60°C
- Ethernet

General Purpose Devices

A number of general purpose devices were identified through a quick search that at least partially fulfill our general requirements. Note that Ethernet is not included in the chart since only devices with Ethernet interfaces were considered.

Table 1: General Purpose Devices versus Requirements

Device	Linux and Python	LCD interface	Removable storage >= 4GB	1U rack-mount	Fanless	Extended temperature
Adlink MXE-1005	•		•		•	optional
Advantech UNO-1019	•		•		•	
Advantech UNO-1140	•		•		•	•
Advantech FWA-3305	•	•	•	•		
Artila Matrix-520	•	No buttons	•		•	
Axiomtech rBox104	•		•		•	•
Axiomtech tBox311-820-FL	•		•		•	•
BSI EMS6503			•		•	•
BSI IOVU-430M		•	•		•	•
Eurotech Helios	•		•		•	•
Kontron MICROSPACE MPCX28R	•		optional		•	•
Korenix JetBox 3350i-w	•		•		•	•
Korenix JetBox 9430-w	•		•		•	•
Sealevel Relio R9			•		•	•
Sealevel Relio R4300	•		•	•	•	
Stealth LPC-125LPFM	•				•	
UEI DNA-PPCx	•		•		•	•

Adlink

MXE-1005:

- Intel Atom N270 CPU @ 1.6 GHz
- 1 GB RAM
- Fanless
- No LCD or buttons
- One 10/100/1000Mbps Ethernet
- Four USB ports
- Two RS-232 serial ports, two RS-232/422/485 serial ports
- One VGA video out port
- CompactFlash slot, SATA port
- No documented installed OS, supports Linux and Windows
- Operating temperature: 14° to 140° F (-10° to 60° C),
  -4°to 158° F (-20° to 70° C) optional
- Price: N/A
- Source: http://www.adlinktech.com/PD/marketing/Datasheet/MXE-1000Series/MXE-1000Series_Datasheet_en_1.pdf

Advantech

UNO-1019:

- Marvell XScale ARM-5 CPU @ 200 MHz
- 64 MB RAM
- Fanless
- No LCD or buttons
- Two 10/100 Mbps Ethernet
- No USB
- Two RS-232 serial ports, two RS-232/422/485 serial ports
- No video out port
- CompactFlash slot
- Windows CE 5.0, optional µClinux
- Operating temperature: 32° to 158° F (0° to 70° C)
- Price: $425.00
- Source: http://downloadt.advantech.com/ProductFile/Downloadfile4/GF-X1LP/UNO-1019_DS.pdf

UNO-1140:

- Advantech 486SX CPU @ 150 MHz
- 64 MB RAM
- Fanless
- No LCD or buttons
- One 10/100 Mbps Ethernet
- Two USB ports
- Four RS-232/485 serial ports
- One VGA video out port
- CompactFlash slot
- Optional Windows CE.NET 6.0, DOS, Linux
- Operating temperature: -4° to 167° F (-20° to 75° C)
- Price: $365
- Source: http://downloadt.advantech.com/ProductFile/PIS/UNO-1140/Product%20-%20Datasheet/UNO-1140_DS20110706140617.pdf

FWA-3305:

- Intel Atom CPU @ 1.66 GHz
- Up to 4 GB RAM
- LCD interface
- Six 10/100/1000 Mbps Ethernet
- Two USB ports
- One RS-232 console serial port
- One SATA drive bay, One CompactFlash slot
- Supports Windows and Linux
- Operating temperature: 32° to 104° F (0° - 40° C)
- Price: $750
- Source: http://downloadt.advantech.com/ProductFile/PIS/FWA-3305/Product%20-%20Datasheet/FWA-3305_DS20111114113500.pdf

Artila

Matrix-520:

- ATMEL ARM-9 CPU @ 180 MHz
- 64 MB RAM
- Fanless
- 18x2 character LCD, no buttons
- Two 10/100Mbps Ethernet
- Two USB ports
- Five RS-232/422/485 serial ports, Three RS-232 serial ports
- No video out port
- SD card slot
- Watchdog timer, buzzer
- Linux 2.6 OS
- Operating temperature: 32° to 158° F (0° to 70° C)
- Price: N/A
- Source: http://www.artila.com/dshtml/Matrix-520.html

Axiomtech

rBox104:

- Intel Atom CPU @ 1.1 GHz
- Up to 2 GB RAM
- Fanless
- No LCD or buttons
- One 10/100/1000 Mbps Ethernet
- Two USB ports
- Two RS-232/422/485 serial ports
- One VGA out port
- CompactFlash slot, optional SD card slot
- Two watchdog timers, alarm contact, user defined alarm LED
- Supports WinCE, Linux, Windows® 7
- Operating Temperature: -40° to 158° F (-40° to 70° C)
- Price: N/A
- Source: http://us.axiomtek.com/Download/Spec/rbox104.pdf

tBox311-820-FL:

- Intel Atom CPU @ 1.1 GHz
- Up to 2 GB RAM
- Fanless
- No LCD or buttons
- Two 10/100/1000 Mbps Ethernet
- Four USB ports
- No serial ports
- Two VGA video out ports
- One SATA drive bay, one CompactFlash slot
- Watchdog timer, 4 programmable LEDs
- Supports WinCE, Linux
- Operating Temperature: -40° to 149° F (-40° to 65° C)
- Price: N/A
- Source: http://us.axiomtek.com/Download/Spec/tbox311-820-fl.pdf

BSI

EMS6503:

- Intel Atom @ 1.1 GHz
- Up to 2 GB RAM
- Fanless
- No LCD or buttons
- One 10/100/1000 Mbps Ethernet
- Four USB ports
- Two RS-232 serial ports
- One VGA video out port
- One SATA drive bay, one CompactFlash slot
- Watchdog timer
- Supports Windows XPE
- Operating temperature: -4° to 149° F (-20° to 65° C)
- Price: $805
- Source: http://www.bsicomputer.com/new/embedded_computer/ems6503/ems6503_embedded_computer.htm

IOVU-430M:

- Intel XScale RISC CPU @ 416 MHz
- 128 MB RAM
- Fanless
- Touch sensitive LCD
- One 10/100 Mbps Ethernet
- One USB port
- One RS-232/422/485 serial port
- miniSD card slot
- Windows CE 5.0
- Operating temperature: -4° to 140° F (-20° to 60° C)
- Price: N/A
- Source: http://www.bsicomputer.com/new/panel_PC/iovu430m/iovu430m_touch_panel_pc.htm

Eurotech

Helios:

- Intel Atom @ 1.1 GHz
- 512 MB RAM
- Fanless
- No LCD or buttons
- One 10/100/1000 Mbps Ethernet
- Five USB ports (3 inside bay)
- One RS-232/485 serial port
- Optional multimedia card for video out
- 2 GB CompactFlash card (optional SD card, optional internal SATA drive)
- Eight programmable LEDs, one software readable push button
- Wind River Linux 3.0, Windows CE 6.0
- Operating temperature: -40° to 185° F (-40° to 85° C)
- Price: N/A
- Source: http://www.eurotech.com/DLA/datasheets/Products_Eurotech/HeliosPlatform_sf.pdf

Kontron

MICROSPACE MPCX28R:

- Intel Atom CPU @ 1.6 GHz
- 1 GB RAM
- Fanless
- No LCD or buttons
- Two 10/100 Mbps Ethernet
- Five USB ports
- Two RS-232/422/485 serial ports
- One DVI video out port, VGA optional
- One SATA bay, optional CompactFlash
- Compatible with Windows or Linux
- Operating temperature: -4° to 158° F (-25° to 70° C)
- Price: N/A
- Source: http://us.kontron.com/_etc/scripts/download/getdownload.php?downloadId=MTEzNDY=

Korenix

JetBox 3350i-w:

- Atmel ARM CPU @ 180 MHz
- 64 MB RAM
- Fanless
- No LCD or buttons
- Two 10/100 Mbps Ethernet
- Two USB ports
- Two RS-232/422/485 serial ports
- No video out port
- One microSD slot
- Watchdog timer
- Linux
- Operating temperature: -40° to 176° F (-40° to 80° C)
- Price: N/A
- Source: http://www.korenix-usa.com/pdfs/JetBox3350i-w-low.pdf

JetBox 9430-w:

- Intel XScale IXP435 RISC CPU @ 667 MHz
- 128 MB RAM
- Fanless
- No LCD or buttons
- Five 10/100 Mbps Ethernet
- Three USB ports
- No serial ports
- No video out port
- One SD card slot, one CompactFlash card slot
- Watchdog timer
- Linux 2.6.20
- Operating temperature: -40° to 176° F (-40° to 80° C)
- Price: N/A
- Source: http://www.korenix-usa.com/pdfs/JetBox9430-w-low.pdf

Sealevel

Relio R9:

- Atmel ARM CPU @ 180 MHz
- 64 MB RAM
- Fanless
- No LCD or buttons
- One 10/100 Mbps Ethernet
- Two USB ports
- Four RS-232/422/485 serial ports, One RS-485 serial port
- 24-bit TFT LCD controller
- One SD card slot
- Windows CE 6.0
- Operating temperature: -40° to 185° F (-40° to 85° C)
- Price: $799
- Source: http://www.sealevel.com/store/computing-hmi/embedded-risc/embedded-risc-computer/relio-r9-arm9-embedded-risc-computer.html

Relio R4300:

- AMD Geode CPU @ 500 MHz
- 1 GB RAM
- Fanless
- No LCD or buttons
- Two 10/100 Mbps Ethernet
- Two USB ports
- Two RS-232/422/485 serial ports, two RS-232 serial ports
- One VGA video out port
- One optional internal hard drive, one CompactFlash slot
- Watchdog timer
- Windows and Linux compatible
- Operating temperature: 32° to 122° F (0° - 50° C) (Extended temperature options available)
- Price: $999
- Source: http://www.sealevel.com/store/computing-hmi/industrial-computers/expandable-rackmount/r4300-relio-r4300-500mhz-amd-geode-lx800.html

Stealth

LPC-125LPFM:

- Intel Pineview CPU @ 1.8 GHz
- Up to 4 GB RAM
- Fanless
- No LCD or buttons
- One 10/100/1000 Mbps Ethernet
- 4 USB ports
- Two RS-232 serial ports
- One VGA video out port
- 55 GB internal SSD hard drive
- Windows and Linux compatible
- Operating temperature: 14° to 113° F (-10° to 45° C)
- Price: $895
- Source: http://www.stealth.com/littlepc_125_lowpower_fanless_mobile.htm

United Electronic Industries

DNA-PPCx:

- Freescale MPC5200 CPU @ 400 MHz
- 128 MB RAM
- Fanless
- No LCD or buttons
- Two 10/100 Mbps Ethernet
- No USB host ports
- One RS-232 serial port
- No video out port
- 128 MB internal flash, SD card slot
- Windows and Linux compatible
- Operating temperature: -40° to 185° F (-40° to 85° C)
- Price: $995
- Source: http://www.ueidaq.com/media/catalog/product/pdf/datasheet/dna-ppcx.pdf

Advanced Transportation Controllers

For the sake of completeness we are also including information on several Advanced Transportation Controllers (ATCs). At this time it is unknown if these are viable platforms for the ASWC. The ITE Advanced Transportation Controller (ATC) Standard Version 5.2b calls for Linux capability on ATCs and there are several such devices on the market.

Source: http://www.ite.org/standards/ATCcontroller/ATC_5.2b_Comments_Full_4.pdf

McCain

ATC eX 2070

Linux

Freescale PowerQUICC II Pro microprocessor

16MB Flash memory

128MB DDR RAM (expandable)

2MB non-volatile SRAM

Backup real-time clock (RTC)

SDLC ports (2)

Serial (asynchronous) (4)

ENET 1: 100 Base-T Ethernet switch, 1 uplink and 3 additional ports

ENET 2: 100 Base-T Ethernet port dedicated for local communications (i.e. laptop or similar)

USB ports (2)

Display: 8 lines x 40 characters

Keyboard: 3 x 4 navigation and 4 x 4 data entry keypads

Style:	Caltrans 2070
Dimensions:	7" H x 19" W x 13" D (rounded to the nearest inch)
Form Factor:	19" EIA (Electronics Industry Alliance) rack mount
Power:	89 VAC to 135 VAC, 60 Hz (± 3 Hz)
Environment:	Operating Temperature: -37° C to +74° C Humidity: 0 to 95% (non-condensing)
Weight:	12 lbs (depends on final module configuration

Options:

- 256MB DDR memory expansion
- Optional modules
- Various modems (2070 form factor)
- GPS module

Source: http://www.mccain-inc.com/traffic/item/controllers/atc-ex-2070.html

Intelight

NEMA TS2 Type 1 & 2 Advanced Transportation Controller (ATC)

- Compliant with current NEMA TS2 and ATC 5.2b standards
- Open Architecture Embedded Linux Multi-Processing Operating System
- 4 Standard 10/100 Mbit Ethernet Ports
- 2 Quad 4 Port Integral Ethernet Switches
- 4 USB Ports
- 2 Keypads & 8 Programmable Special Function Keys
- ATC 5.2b Compliant Engine Board CPU
- ATC Standard API for third party application support
- Two ATC/2070 Type Communications/Modem Slots
- 16 Line X 40 Character (240 X 120 Graphics) LCD Display
- 7 configurable Serial Ports (5 are SDLC capable)
- 14 3/4” W X 7 3/4” D X 10 1/2” H
- Power 95 - 250 VAC 50/60 Hz Auto Sensing
- -40 to +80° C operating environment
- 64MB Flash / 64MB DRAM memory / 1MB SRAM

Source: http://www.intelight-its.com/dnn/Portals/0/NEMA_TS2_Type_1_&_2%20Cutsheet.pdf

Transportation Control Systems

ATC-2000 Transportation Controller

- Meets the ITE / AASHTO / NEMA ATC standard
- 40 character x 16 line Backlit LCD Display
- Linux Operating System with memory management for process isolation
- 300MHz Freescale Power Quix 2 processor
- Four 100Base -T Ethernet ports
- High speed USB port
- 32 key soft-touch keypad for front panel programming
- Speaks NTCIP protocol. Compliant NTCIP database
- Programmable using the front panel, via IQ LInk or IQ Central, Data Key, or via a USB Thumbdrive
- 5 serial ports, with RS485 support on one port. (The port that functions as the RS485 port is jumper selectable)
- Internal voltage monitoring, power supply voltage readings are available on the LCD screen
- Internal temperature sensor
- 16MB Flash memory (standard)
- 16MB SDRAM memory (standard)
- 32MB and 64MB available as upgrade options
- 1MB SRAM
- Dimensions: 14¾” Wide × 10½” Deep × 10¼” Tall (375mm × 267mm × 261mm)
- Power requirements 95 to 135VAC 60Hz ± 3 Hz
- Environment: -35°F to + 165°F -37°C to + 74°C
- 0-95% relative humidity

Source:

http://www.tcstraffic.com/product_info.php?cPath=30&products_id=96

http://www.tcstraffic.com/product_docs/ATC2000Datasheet.pdf

Siemens

2070L ATC

Linux operating system

- 266MHZ processor on the engine board, the 2070L ATC is faster than the 2070 ATC engine board, with a substantial increase to 16MB flash memory and 64 Mb DRAM. It also includes:
- A rack-mounted or shelf design
- Back-of-cabinet wiring and access
- USB 1.1 port on the front of the controller
- Approved by Caltrans - Latest QPL
- Open Architecture insures compatibility with off-the-shelf products
- VME Hardware (VME chassis not included on the "lite" version)
- Standard VME interface modules from multiple vendors
- Standard OS-9™ Operating System
- Standard software modules from multiple sources
- Added VME boards and software extensions upgrade system easily
- 2 slots available for choice of dual serial, FSK, and fiber optic, EIA232 or 485 modems
- Multitasking - each 2070ATC unit can control multiple applications
- Multiprocessing - each 2070ATC unit can accommodate multiple CPUs
- High speed serial communications to CPU
- Designed and built for unattended operation in harsh environments
- Built-in 10 Base-T Ethernet with IP address on 2070-1B (2070L models)

Source: http://www.interprovincial.com/files/controllers/Siemens%202070.pdf

SITRAFFIC® Sphere ATC

Freescale Power Quicc II Pro microprocessor w/ e200 core, running at 500MIPs with E200 core 266 MHz processor

- 36MB flash memory
- 64 MB DRAM
- 2 MB SRAM
- Linux operating system using gLibc w/ C++ support libraries
- Multi-line alpha-numeric backlit display
- Durable front coating
- Runs multiple-concurrent applications
- Lightweight, injection molded, high-impact poly-carbonate case (rack mount)

Source: http://www.itssiemens.com/en/u_nav1124.html