SAFE-PASSAGE

Development and Demonstration of a Rural Weather Prediction Model and Motorist Communication System for Safe and Efficient Traffic Management/Infrastructure Maintenance

by

John M. Mounce, Ph.D., P.E.

Western Transportation Institute

College of Engineering

Montana State University – Bozeman

In cooperation with the

U.S. Department of Transportation Research and Special Programs Administration

Washington D.C.

September 2, 2003

ABSTRACT

The goal of the SAFE-PASSAGE project was to improve motorist safety and incident management on a 30-mile segment of Interstate 90 between Bozeman and Livingston, Montana. Three primary objectives were identified: (1) to validate and implement a computer model to micro-forecast pavement temperatures and roadway conditions; (2) to provide real-time motorist information through the implementation and effective operation of a roadway communication system, using Variable Message Signs, Highway Advisory Radio, and cellular phone mediums; and (3) to establish a rural Traffic Management Center for reception, coordination, and dissemination of all relevant data between responsible agencies.

This document provides a brief summary of the planning, design, and implementation activities from the first four years of the study, but focuses primarily on activities completed during the fifth and final year of the project. Analysis of crash data before and after the implementation of intelligent transportation system technologies was used to quantitatively measure system effectiveness. Qualitative measures of effectiveness included comments received from motorist surveys, and assessments of the extent to which the roadway communication system was managed and utilized.

DISCLAIMER

The SAFE-PASSAGE project is a cooperative effort by the Western Transportation Institute of Montana State University-Bozeman and the Montana Department of Transportation with funding provided by the Research and Special Programs Administration of the U.S. Department of Transportation. The contents of this paper reflect the views of the author(s) who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the U.S. Department of Transportation, Montana Department of Transportation, or the Western Transportation Institute of Montana State University-Bozeman.

ACKNOWLEDGEMENTS

The author would like to express gratitude to the following individuals for their assistance with this report.

Ms. Nancy Hatfield	Mr. Steve Albert
Ms. Brenda Narro	Ms. Jeralynn Brodoway
Ms. Leslie Stengele	Mr. Pierre Jomini
Ms. Allison Morton	Ms. Tanya Schmidt
Ms. Karen Hernandez	Ms. Jamie Helmith
Dr. Ed Adams	Ms. Carla Little

TABLE OF CONTENTS

1. List of Tables ... vi
2. List of Figures ... vii
3. Introduction ... 8
   - 3.1. Background ... 8
   - 3.2. Corridor Description ... 8
   - 3.3. Project Goal and Objectives ... 9
4. Pavement Temperature Prediction Model ... 10
   - 4.1. Overview ... 10
   - 4.2. Institutional Challenges ... 17
   - 4.3. Summary ... 17
5. Motorist Communication System ... 19
   - 5.1. Background ... 19
   - 5.2. First Year Activity ... 19
   - 5.3. Second Year Activity ... 21
   - 5.4. Third Year Activity ... 21
   - 5.5. Fourth Year Activity ... 21
   - 5.6. Final Year Activity ... 22
   - 5.7. Institutional Challenges ... 23
   - 5.8. Summary ... 23
6. Rural Traffic Management Center ... 25
   - 6.1. Background ... 25
   - 6.2. First Year Activity ... 25
   - 6.3. Second Year Activity ... 25
   - 6.4. Third Year Activity ... 26
   - 6.5. Fourth Year Activity ... 26
   - 6.6. Final Year Activity ... 26
   - 6.7. Institutional Challenges ... 27
   - 6.8. Summary ... 27
7. Evaluation of Measures of Effectiveness ... 28
   - 7.1. Overview ... 28
   - 7.2. Historical Data ... 28

7.3. Crash Analyses 28
7.4. Institutional Challenges 38
7.5. Summary 39
8. Conclusions and Recommendations 40
8.1. Conclusions 40
8.2. Recommendations 41
9. Appendix A: Bozeman Pass Pavement Temperature Forecast Model Evaluation 42
10. References 43

1. LIST OF TABLES

Table 1: Monthly Frequencies of VMS Message Content 2002 23

Table 2: Reported Weather Conditions for Crashes Before an After SAFE-PASSAGE Implementation 29

Table 3: Reported Road Conditions for Crashes Before and After SAFE-PASSAGE Implementation 30

Table 4: Consequential Relationship of Weather to Crashes Before and After SAFE-PASSAGE Implementation 30

Table 5: Severity of Crashes Before and After SAFE-PASSAGE Implementation 31

Table 6: Weather Related Crashes by Mile Marker and Year 32

Table 7: Wind-Related Crashes by Mile Marker and Year 34

Table 8: Snowstorm-Related Crashes by Mile Marker and Year 35

Table 9: Road Condition- Related Crashes by Mile Marker and Year 36

Table 10: Snow/Slush Road Condition Related Crashes by Mile Marker and Year 37

Table 11: Relevancy of VMS Messages to Conditions Contributing to Crashes 38

Table 12: Annual Frequencies of Secondary Crashes 38

2. LIST OF FIGURES

Figure 1: Tri-Color Map of the Study Corridor 15
Figure 2: Terrain Thermal Map of Study Area 16
Figure 3: SAFE-PASSAGE Corridor Motorist Communication Sites 20
Figure 4: Total Crashes by Milepoint 1996-2002 31

3. INTRODUCTION

3.1. Background

The Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO) have advocated measures to enhance transportation safety for over 30 years (1,2). In particular, the need to minimize roadway hazards and warn motorists of unsafe conditions has been the focus of considerable research and discussion. According to the National Transportation Safety Board (NTSB), hazards associated with adverse weather conditions should be given a high priority in countermeasure selection and implementation (3).

Research conducted in the late 1970's concluded that Variable Message Signs (VMS) and Highway Advisory Radio (HAR) were effective technologies for providing timely advisory messages to travelers (4,5). Furthermore, the most recent federal transportation appropriations bill, the Transportation Enhancement Act (TEA-21), emphasized the potential safety applications of Intelligent Transportation System (ITS) technologies in rural areas. Many states, including Montana, initiated efforts to obtain timely and accurate weather information, and implemented communication systems to convey that information in real-time to motorists.

The SAFE-PASSAGE project described in this document, which was developed in response to the concerns described above, incorporates selected ITS technologies in the study design. The project was initiated as a cooperative effort between Western Transportation Institute, Montana State University-Bozeman and the Montana Department of Transportation (MDT). The Research and Special Programs Administration of the U.S. Department of Transportation through the Western Transportation Institute provided funding for the project. Four previous annual reports documented the planning, design, and implementation activities that occurred in 1999, 2000, 2001, and 2002 respectively (6,7,8,9). This document provides a brief summary of previous accomplishments, but focuses primarily on activities completed during the fifth year of the project, as well as documenting overall trends, findings, and recommendations.

3.2. Corridor Description

The SAFE-PASSAGE study corridor is a 30-mile section of Interstate 90 between Bozeman and Livingston, Montana. On a national scale, I-90 is a major east-west corridor between Chicago, Illinois and Seattle, Washington, and as such, represents a vital link in the commercial transportation infrastructure network. The designated study corridor also serves to connect two major north-south access highways (US 89 and US 191) to Yellowstone National Park. On a local level, there are a number of commuters who travel this route on a daily basis.

According to data provided by MDT, the study corridor handles over 100 million vehicle-miles of travel each year, with an Average Annual Daily Traffic (AADT) of approximately 10,000 vehicles (10). Traffic composition was determined over a five-year period to be 16 percent commercial vehicles and 3 percent recreational vehicles and buses, with private automobiles comprising the remaining 81 percent of the traffic stream.

An examination of accidents within the corridor over a five-year period (1994-1999) confirmed an overrepresentation of weather-related motor vehicle crashes. Roughly 70 percent of the crashes had weather conditions reported as a contributing factor by investigating law enforcement officers (11). Furthermore, a 1995 study sponsored by MDT cited weather as one of the three largest contributors to truck accidents in the State and identified the Bozeman Pass section of I-90 as a prime candidate for safety improvement applications (12).

3.3. Project Goal and Objectives

To achieve the ultimate goal of the project, which is to improve motorist safety and incident management on I-90 between Bozeman and Livingston, the following three objectives were identified.

(1) to validate and implement a computer model to micro-forecast pavement temperatures and roadway conditions;
(2) to provide real-time motorist information through the implementation and effective operation of a roadway communication system, using VMS/HAR cellular phone mediums; and
(3) to establish a rural Traffic Management Center for reception, coordination, and dissemination of all relevant data between responsible agencies.

The extent to which project objectives were met was to be determined through subsequent effectiveness evaluations. Potential benefits would include a reduction in the number or severity of motor vehicle crashes within the corridor, more efficient roadway maintenance activities, and improved coordination of communication procedures and emergency response activities.

The ability to detect significant differences in these and other measures of effectiveness following the implementation of the SAFE-PASSAGE components would depend, in large part, on having sufficient data available for meaningful before/after comparisons. Qualitative evaluations, including anecdotal information from system users or motorists traveling through the corridor could be useful for providing preliminary assessments of project effectiveness.

4. PAVEMENT TEMPERATURE PREDICTION MODEL

4.1. Overview

The thermal analysis for calculating the highway pavement temperature for the SAFE-PASSAGE project is an outgrowth of an earlier MDT proof of concept study carried out under the MDT-MPART program (13). A first-principles approach (that is, based on the physical principles, rather than statistical data), was demonstrated in the earlier study to offer a viable approach to the roadway thermal mapping problem. The concept behind the approach is that by coupling meteorological data with topographic orientation and terrain thermal properties, the surface temperature of the terrain, including specifically the highway, may be modeled with reasonable accuracy. Shadowing, surface-to-surface radiation exchange, and elevation all have an impact on the road temperature.

The computational highway thermal map is an outgrowth of software developed for the U.S. military to determine the thermal signature of vehicles. This concept uses planar elements of finite thickness, called facets, to define the geometry. An important concept from the outset is that the program be highly transportable in the sense that another section of highway can be modeled in a straightforward manner.

The concept behind the modeling effort is based on the adaptations of a computational model used by the U.S. military for the prediction of vehicle infrared images. The one-dimensional, first-principles heat transfer software from which the pavement model is derived originated from two sources: the TCM (Thermal Contrast Model) originally developed for the U.S. Air Force (14, 15), and PRISM (Physically Reasonable Infrared Signature Model) developed at the Michigan Technological University's Keweenaw Research Center in conjunction with the U.S. Army Tank-Automotive Command (TAMCOM) (16). These programs were developed as a tool to model the surface temperatures of vehicles for use in infrared imagery. The infrared signature of a vehicle, in essence, indicates the characteristic surface temperatures of a vehicle subjected to a set of meteorological conditions. Vehicles are composed of homogeneous manmade materials of complex geometry. The modeling approach employed in this capacity essentially constructs the three-dimensional vehicle by defining a surface composed of a collection of facts. The landscape in these models was considered simply as a background and treated in the model as an isothermal, flat plane.

The facet concept was extended to backgrounds to examine thermal processes in a topologically varied snow cover (17), including surface condensation and sublimation (18). Recent developments in Geographic Information Systems (GIS), along with the widespread availability of Digital Elevation Maps (DEM), now offer the potential for practical implementation of a terrain model. Highway safety is an area in which pavement implementation is of practical importance. It determines, among other things, ice accretion, and it is a vital component in the effective implementation of deicing and anti-icing programs. (19,20,21).

Computationally, one-dimensional, finite difference heat conduction equations are solved in the direction of the surface normal, to determine the temperature profile through the thickness of each of the facets. Boundary conditions used to solve the equations assume a fixed temperature for the lower bound and a derivative condition for the heat flux at the upper surface. The upper energy exchange includes solar heating, radiation, convection and phase change. Surface orientation takes into account diurnal solar variation including shadowing, and facet-to-facet long-wave radiation exchange.

Surrounding landscape features including aspect and elevation, along with surface material properties, including vegetation, exposed soil rock or snow all influence the pavement temperatures. The effects that shadowing surface-to-surface radiation have on pavement temperature are determined by the thermal properties of the surrounding terrain, such as albedo, emmisivity, and conductivity. Each facet has a view factor defined, which essentially is what it would "see looking out," given its orientation with respect to the sky and other facets making up the landscape. These view factors are used to incorporate shadowing, sun angle and the orientation for surface-to-surface radiation.

The ongoing development effort for the road temperature modeling has been carried out in close cooperation with ThermoAnalytics, Inc. The original moniker for the program was WinThermRT to reflect the Windows platform under which it was being developed. Subsequently, it was renamed RadThermRT to better indicate the particular strength of the model in being able to deal with the complicated effects of radiation in complex topography when calculating the "road temperature."

The original intent of the pavement thermal model for the SAFE-PASSAGE project was to make use of a Road Weather Information System (RWIS), a roadside meteorological station on the top of Bozeman Pass, to calculate the spatially and temporally varying road temperatures on Interstate 90 between Livingston and Bozeman, Montana. It was envisioned that the RWIS data might be coupled with other existing meteorological stations, such as the RWIS located east of Livingston and Bozeman and the Livingston Airport, to extrapolate meteorological conditions varying with elevation. This approach would constitute a "now-cast" or, more accurately, a "slight past-cast." However, in that the calculated output would yield temperatures every 30 meters along the highway in addition to the single-point highway temperature measured at the RWIS, it was felt that this information would constitute a useful tool in the winter highway arsenal for road safety operations. In essence, this approach would spatially extend the data currently used in MDT's decision-making process. Once this approach was operational and validated, it was anticipated that the forecasts that SSI provides for its RWIS sites might be incorporated to produce a road temperature forecast, particularly if a pass was bracketed with forecasts from other RWIS sites. This project is considered a step in an ongoing process to address the highway thermal mapping problem.

Among the critical meteorological input parameters for this modeling effort are radiation values. In fact, the ability to incorporate radiation for a complex terrain in the calculations is the aspect from which this thermal modeling effort derives its unique merit.

Radiation data, however, are not standard at the SSI-RWIS stations. Although assurance was given to WTI that adding sensors to the station would not prove problematic, a number of difficulties were encountered which were outlined in earlier reports on the SAFE-PASSAGE Project. MDT has recently taken over greater control of the system of RWIS stations, and radiation data from Bozeman Pass have since become available.

In fact, as has been pointed out in previous reports, the entire process of applying the RWIS data to develop and validate the thermal model was never accomplished, as anticipated. Unfortunately, the requisite data, including the necessary radiation data, were never available for acquisition in a timely fashion and in a usable format. This limitation substantially altered the approach to the modeling effort. In order to continue development of the pavement thermal model, a protocol was developed to download stored data and a separate data logger was placed at the RWIS location that had to have data downloaded on site. The data logger used to record the short wave (solar) radiation and the long wave (IR) radiation was modeled, based on estimated cloud cover for much of the period under consideration. When it became apparent that the anticipated real-time meteorological data sought from the RWIS were not going to be forthcoming, other approaches to acquiring the requisite data were sought.

Another critical parameter for calculating the convective heat transfer component, and one that has high spatial variability in complex topography, is the wind. Dr. Peter Gauer joined the thermal modeling research team to examine the potential for using Computational Fluid Dynamics (CFD) computer codes to model the orographically influenced winds, as they pertained to the thermal model under development. Dr. Gauer was brought in because he had expertise in using CFD codes to model wind fields in mountainous terrain. While at the Swiss Federal Institute for Snow and Avalanche Studies, he had been heavily involved in computational modeling of the wind-borne snow transport phenomena. As a result, he was uniquely qualified to apply the CFD approach to Aeolian processes in mountainous terrain. It was determined later that the use of codes of this sort was too computationally time-consuming to be efficiently utilized for real-time application to the thermal model in a temporally expedient manner, as required for this highway application.

In light of the need to acquire weather data to substitute for the unavailable RWIS data, Dr. Gauer recommended the mesoscale meteorological forecast model, known as the Advanced Regional Prediction System (ARPS), be selected for assessment for use as an input set to the thermal model. ARPS was developed and is maintained and updated by the University of Oklahoma Center for Analysis and Prediction of Storms in the School of Meteorology. The system is considered to be an excellent code when dealing with mesoscale forecasts in complex terrain. In addition, no licensing fee is required. Using a mesoscale meteorological forecast model provided some very obvious advantages, as well as some significant challenges.

Given its nature as a weather forecast model, the code offers the clear advantage of providing a means for running a true forecast for the calculated pavement temperature. This was always envisioned as being the ultimate goal in the evolution of thermal model development, but the more progressive approach considered had been to first provide and verify the now-cast in an operational setting. The sophistication of the forecast model was certainly at a much higher level than what had been anticipated at this stage of research. However, based on the results of the studies using the stored and processed data for the seven- mile segment through Rocky Canyon, the thermal model showed very positive results. This rather large leap forward in the approach, although forced, in a sense, by the circumstance of unavailable data, appeared to be reasonable and, therefore, was pursued. However, it did represent a major shift in the development effort at this stage of the project, and it changed the projected outcome. In the long run, this was likely to be considered a constructive development that significantly accelerated the process beyond what had been the immediate study objective.

Another benefit of the mesoscale ARPS modeling effort was that the meteorological data could be spatially varied over the region of interest, which addressed a critical aspect of the input to the terrain thermal model. The thermal model, itself, had to be reconstructed in such a manner that it could handle a spatially varying weather file. The ability to drive the model using a single weather data point was retained, because it may prove useful when modeling smaller regions or if other data are not available. Even with the single data source, the influence of topography is accounted for through the shadowing and surface-to-surface exchanges; because the location of the sun position is calculated for the given latitude, longitude, date, and time. In essence, the model provides the means to calculate individual weather forecasts at each point in a meteorologically fine grid. In the case of the Bozeman Pass area, a one-km grid was initially chosen as the fine resolution for the weather forecast. This was considered the finest grid that ARPS was capable of reasonably accomplishing. As input to the thermal model, this was then interpolated to the 30-m grid for the surface temperature calculations. This spacing was used because it is the resolution readily available from the United States Geological Society (USGS).

A digital elevation map (DEM) (30-m grid) analytically defines the topography. The Montana State University Geographic Information and Analysis Center (GIAC) configured the map in the specified format for use in the thermal model. Terrain is identified by the type of vegetation and exposed rock, based on data that GIAC acquired from the Wildlife Spatial Analysis Laboratory at the University of Montana.

The modeling chain sequence used for the pavement temperature forecast is as follows. The chain is initiated using a 40-km grid spacing meteorological forecast supplied by the National Weather Service (NWS), based on the Global Climate Model Eta. These values are then used as initial and boundary conditions that are adapted by APRS for the specified fine resolution. In the initial study, a one-km grid was used. These meteorological data were then interpolated in order to achieve the 30-m resolution used by RadThemRT. Finally RadThermRT yields a terrain temperature forecast.

Until January, 2002, all of the modeling was carried out on this site at MSU. Meteorological modeling is notorious for computational cost and could not be carried out with the computer resources available. It should be noted that significant funds were expended from external sources to purchase an 8-processor Silicon Graphics computer to facilitate moving forward in the new direction described. The modeling was carried out on the Rocky Canyon section of I-90 (roughly between Mile Markers 114-119) as described in a previous report (8).

In an effort to more efficiently run the models, and, ideally, increase accuracy from the ARPS modeling work, an agreement was arranged with Meridian Environmental Technology, Inc. of Grand Forks, North Dakota. Meridian is a meteorological company with an emphasis on road weather forecasts and a close relationship with the University of North Dakota. Leveraging work from another project, Meridian agreed to take over the true meteorological aspect of the SAFE-PASSAGE Project (i.e., running the ARPS model).

Work continued steadily from the end of the 2002 winter maintenance season with substantial expansions of the forecast region and the forecast time. Subsequent to ETA data availability, the length of time required to complete the ARPS runs naturally increases with the length of forecast, while the accuracy of the forecast deteriorates the further it is projected. Similarly, the run time for RadThermRT increases with increased forecast time. It was felt, however, that the forecast time should be extended so that information could be provided at times that coincided with the work schedules of MDT Maintenance personnel. More specifically, information should be made available just prior to personnel arriving for work in the morning or just prior to their leaving in the afternoon so that these individuals would have the best opportunity to make decisions about signage and maintenance operations based on the available data.

In addition, the forecast region used for the RadThermRT was extended to include the roadway segment from Mile Marker 314 to Mile Marker 330. An example of the web page displaying the tri-color highway thermal map for the expanded highway section is shown in Figure1.

Figure 2 displays an example of a thermal map, calculated using the modeling chain described previously. It also is revealing to note, in addition to the shadowing and surface-to-surface radiation exchange, the influence of the different terrain materials on the thermal signature.

During the Spring of 2002, all efforts were directed toward connecting the chain of modeling programs in a reliable fashion between NCEP, Meridian, and MSU/WTI, and then in parallel, toward displaying the resulting forecast data on the web in a usable form. A large part of the effort was devoted to reviewing the tools and techniques available for displaying such data in a web-viewable format, which included leaning how to generate animation sequences of graphical displays. As a consequence, very little effort was expended on validating ARPS or RadThermRT forecasts at that time.

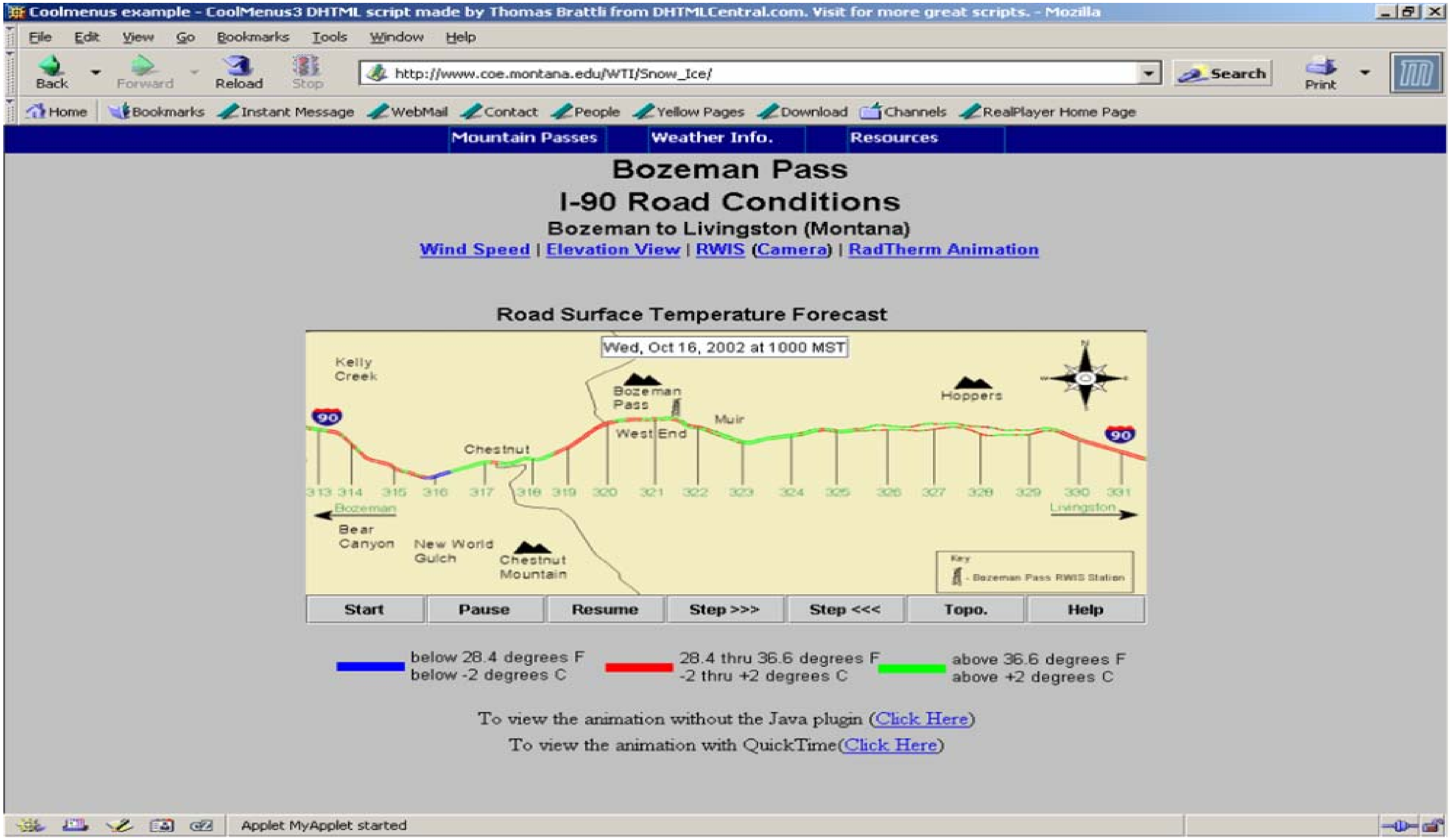

Figure 1: Tri-Color Map of the Study Corridor

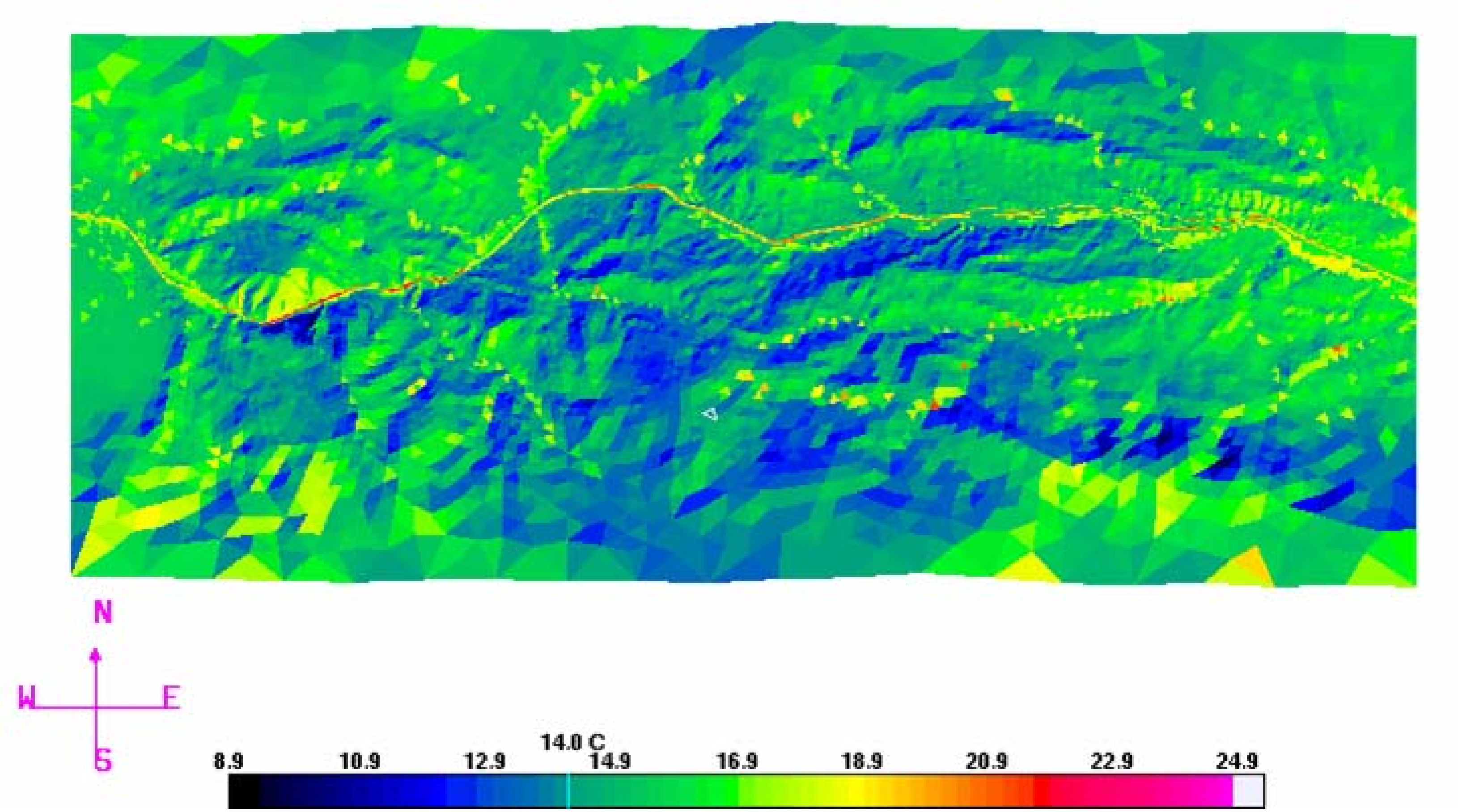

Figure 2: Terrain Thermal Map of Study Area

It should be recalled that during that timeframe, the only RadThermRT model running was for Rocky Canyon, which did not provide a forecast that could be compared with the RWIS at the top of Bozeman Pass. Since then, a RadThermRT model of the entire Pass has been completed and effort was put into building tools and techniques that can be used to evaluate the accuracy of the resulting forecasts. See Appendix A for an evaluation of the Bozeman Pass forecast model.

As discussed in the previous report (8), the accuracy of the road surface temperature forecast is highly dependent on the accuracy of ARPS forecast. When ARPS is accurate, the modeled road surface temperatures are accurate. In some cases, forecast errors balance out so that RadThermRT actually yields a more accurate forecast than does ARPS. Either way, ongoing validation and research will be required to continually improve the accuracy of the chain in weather models.

A website was constructed to display all of the terrain temperature forecast data and the fine-scale meteorological forecast maps. In addition, based on discussions with MDT personnel, a display was added that depicted only the highway temperature, broken down into a tri-color map that emphasized approximate freezing conditions. Red was chosen to indicate values from +2 to -2 C (28 to 36 F). Blue was selected to indicate colder temperatures (i.e., below this range), and green was used for values above this range. Hourly lists of much of the fine-scale meteorological maps, as well as the terrain temperature data, were included for viewing on the web site. Throughout much of this past winter, the web site user was required to open each hour individually, a system that was not considered sufficiently convenient for full utility. By March, these tri-color displays were available as animations. Another option that MDT Maintenance personnel requested was that forecast wind velocities be displayed in some sort of hazard scale alert. This feature also was added in the spring of 2002. The map is essentially the same as that used for the tri-color temperature display but depicts three ranges of wind speed. In this instance, red indicates above 60 mph (27 m/s), blue indicates 30-60 mph (13-27 m/s) and green indicates below 30 mph (13 m/s). MDT Maintenance personnel requested these parameters, which they perceived as critical values, based on their practical experience. This feature was added to the web site late in the Spring of 2002.

4.2. Institutional Challenges

The project team developed and provided an accurate predicted (forecast) pavement temperature information to the Bozeman MDT Maintenance Office through a maintained, user-friendly web site. However, the research staff has no knowledge that this information was ever accessed or utilized for either resource deployment or motorist communication advisories, perhaps as a result of manpower shortages at MDT. Therefore, the capability of this newly developed technology cannot yet be assessed in terms of its impact on motorist safety or agency effectiveness with regard to winter maintenance activities.

4.3. Summary

Within the Safe Passage project, a pavement temperature prediction model was developed, tested, and validated for application accuracy. Validation results for the model have been favorable (see Appendix A for a detailed evaluation) and enhancements are continuing based on requests and recommendations from MDT. Output from the model was made available to MDT maintenance personnel through a user friendly website for the purposes of motorist advisement and resource deployment. Greater use of the data by MDT and further evaluation will be required to determine the model's impact on winter maintenance activities and traveler safety.

5. MOTORIST COMMUNICATION SYSTEM

5.1. Background

The motorist communication system within the SAFE-PASSAGE project is a multi-level approach for providing safety information to travelers while en-route. The three components of the system are variable message signs (VMS), highway advisory radio (HAR), and a toll-free cellular phone number. By overlapping critical information on all three mediums, the potential for travelers to receive, understand, and properly respond to the information is believed to be maximized.

Four variable message signs are located at three sites along the study corridor; the sign at Mile Marker 330.5 is a double sign, one for each direction of travel, with directional single side signs located at Mile Markers 311.0 and 338.6. Each is designed to convey the most essential information concerning potential hazards (i.e., roadway or weather condition), as well as directed response to enhance motorist safety (e.g., speed reduction, chain requirements, or route diversion). VMS coverage extends a minimum of 1,000 feet forward visibility from the sign, or the equivalent of approximately 10 seconds of viewing time at posted highway speeds. (See Figure 3)

Highway advisory radio, with its wider broadcast range, is capable of providing more extensive and detailed information than that conveyed on variable message signs or other static signs. Within the study corridor, HAR coverage extends for several miles at two different locations. (See Figure 3)

The cellular telephone number, which may be referenced by any combination of VMS, HAR, or other static signs, has the widest range of the three mediums and hence, the greatest capability for conveyance of information. Cellular phone reception is available in over 95 percent of the designated 30-mile study section of I-90.

5.2. First Year Activity

With respect to the Motorist Communication System, the first year of the SAFE-PASSAGE project was devoted to VMS and HAR design and to system assessment requirements. VMS locations were selected at Mile Markers 311.0, 330.5, and 338.6 in the study corridor. Based on the functional parameters of conspicuity, legibility, comprehensibility, and credibility, the photometric and physical design requirements for the VMS were established. In addition, basic criteria for the VMS messages were determined. HAR installations were established at Mile Markers 311, 332, and 340. It was decided that each of the three systems would be referenced with both static and VMS signs. Lastly, qualitative and quantitative assessment techniques were developed for subsequent effectiveness evaluations of the motorist communication system (6).

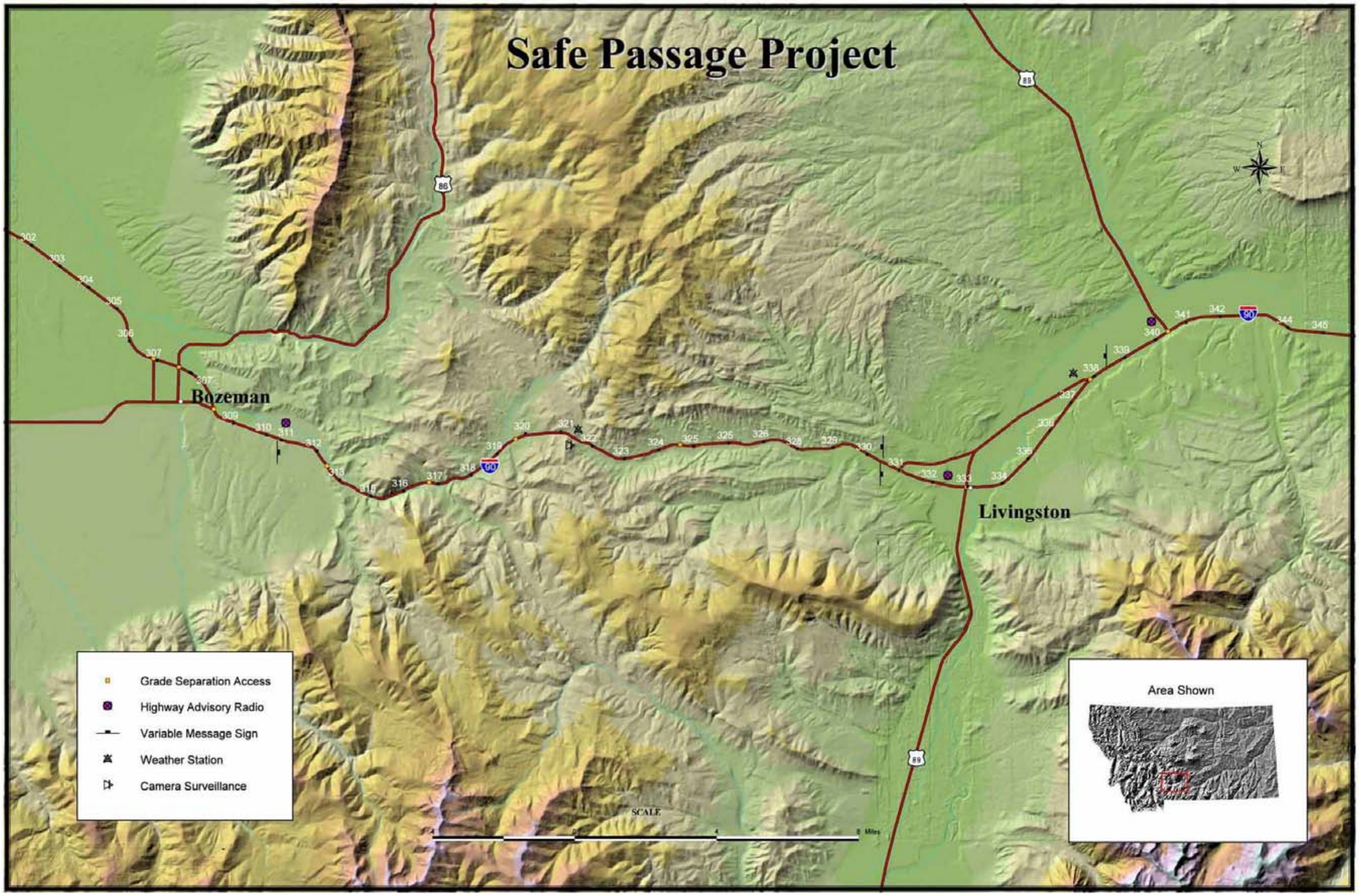

Figure 3: SAFE-PASSAGE Corridor Motorist Communication Sites

5.3. Second Year Activity

Construction activity at the VMS sites was completed, the sign structures erected, and the actual VMS signs installed, although not activated, at all three locations during the second year of the project. A set of advisory messages for VMS and HAR use was developed and revised, as needed, based on comments received from MDT reviewers. Efforts to relocate and upgrade the current HAR systems with digital transmitters to improve signal quality and range were initiated (7).

5.4. Third Year Activity

The VMS signs became operational during the third year of the SAFE-PASSAGE project. Sign usage during the third year was minimal, however, because the signs were not operational until March, after which severe winter weather is less typically a hazard for motorists. Much of the discussion during that time related to whether or not a message should be displayed when a warning or advisory was not warranted, and if so, what message should be utilized. The issue was never fully resolved during the third year of the project.

The major activity during the third year was a preliminary evaluation of the motorist communication system that was conducted via a survey of the motoring public. The overall results showed that travelers of the corridor were well aware of the VMS signs and more than half found the messages to be useful. Also, the vast majority believed that VMS technology is more effective than standard roadside signs as a means of conveying information (8).

5.5. Fourth Year Activity

In the fourth year of the SAFE-PASSAGE project, activities centered primarily on two areas: (1) the frequency, location and content of VMS messages; and (2) a follow-up motorist survey to further assess motorist opinion regarding VMS technology (9).

Within the 15-month period following VMS implementation, messages were displayed a total of 445 times, with warnings related to snow or ice being the single most frequently posted message. Messages related to accidents were severely under-utilized; although 134 accidents were reported along the study corridor during this time period, corresponding messages were displayed on only six occasions. Based on results of the initial motorist survey, the default option for the VMS was changed from displaying the statewide road information toll-free telephone number to a blank sign.

Previously prepared messages to be displayed by VMS were rarely, if at all, utilized. Message content was inconsistent for a similar situation of advisement and did not comply with national guidelines or protocol. In addition HAR relocation for improved transmission on was not undertaken by MDT.

The rationale for conducting the follow-up motorist survey is described in detail in the fourth year final report, as well as the survey instrument, survey protocol and distribution sites (9). Of the 3,000 surveys distributed in 2002, 811 were completed and returned for a 27% response rate. Motorists were classified into traveler groups on the basis of trip frequency and self-assessed familiarity with the designated route.

The vast majority of respondents felt VMS were more effective than static highway signs at conveying information. In terms of the importance and appropriateness of VMS message, overall ratings of 4.05 and 3.95 on a five-point scale were provided. The timelines of the information received a somewhat lower rating (3.87), whereas overall ratings were highest for the ease of reading and understanding VMS messages (4.19 and 4.34, respectively). Not surprisingly, those motorists with relatively less exposure to the signs gave lower ratings to reading and understanding VMS messages. In particular, two-part messages were found to be difficult to read when traveling at the posted speed limit, according to written comments on the survey.

Motorists were asked to select the two most important types of information from the following four options: weather/road conditions; accidents/road hazards; construction/ maintenance activities; and traveler services information. Messages pertaining to weather/road conditions were selected most often, followed by information regarding accidents/other road hazards. Traveler services information was rarely requested, which was consistent with written comments that stated only critical messages should be displayed.

In general, the written comments on the follow-up survey were very comparable to those received in the initial survey. Motorists were critical of inaccurate or untimely messages, as well as messages perceived as too general or intuitively obvious to be useful. Complaints were received about the cost of the technology, and motorists assumed that a blank sign, which was used as the default condition when no hazardous conditions existed, was an indication the VMS was malfunctioning. Positive feedback was received concerning the technology's ability to provide current information and the enhanced conspicuity of the VMS.

5.6. Final Year Activity

The VMS signs have been in operation since March 2001. For the 22-month period from March 1, 2001 through December, 2002, the data logs have been accessed and sign activity documented. Since the signs became operational, over 100 different messages have been displayed on the VMS. Table 1 displays a breakdown of the different messages by category and month. For the period January 2002 through December 2002, note that the total number of messages in Table 1 is considerably greater than 100, because some of the messages displayed were dual purpose (e.g., a message that warned of snow and ice also may have contained information regarding plowing operations). By far, the most frequently posted message related to snow and ice, which was displayed on almost 200 occasions during 2002. As in the previous year, it should be noted that very few accident messages were displayed. In fact, only ten messages related to accidents were posted, although 158 accidents were reported along this portion of I-90 during 2002.

As previously stated, VMS installations within the SAFE-PASSAGE corridor are located at Mile Marker 311 eastbound, Mile Marker 330 eastbound, Mile Marker 330 westbound, and Mile Marker 338 westbound. The VMS display at Milepost 311 was utilized most often for motorist communication, with messages changed 170 times during 2002. For the signs at Mile Markers 330 eastbound, 330 westbound, and 338 westbound, the messages were changed 119, 111, and 127 times, respectively.

Table 1: Monthly Frequencies of VMS Message Content 2002

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Other	5	2	8	0	0	0	0	4	0	6	4	5	34
Crash	0	0	3	0	0	1	3	0	0	1	0	2	10
Snow/Ice	61	34	40	19	20	0	0	0	0	2	4	12	192
Plows	35	22	23	12	18	0	0	0	0	2	4	10	126
Visibility	7	5	15	5	0	0	0	0	0	0	0	0	32
Wind	41	80	42	7	0	0	6	5	0	0	6	26	213
Wet	4	5	2	6	2	2	0	0	2	0	0	0	23
Fire	0	0	0	0	0	0	0	0	0	0	0	0	0
Const/Maint.	1	2	3	4	13	11	13	7	0	14	15	0	83
Total	154	150	136	53	53	14	22	16	2	25	33	55	713

5.7. Institutional Challenges

Since its implementation in March 2001, the VMS system within the SAFE-PASSAGE corridor of I-90 has been operated without any procedural guidelines. Displayed messages have been inconsistent, and often untimely with regard to when the message was initiated and/or removed. Message content has not followed accepted national (FHWA) protocol and the responsibility for message selection and wording for hazardous situations was given to various untrained staff from the Bozeman MDT Maintenance Office. WTI did not receive additional administrative support from MDT in terms of policy guidance, manpower, time, or fiscal resources to address these challenges. Therefore, the potential effectiveness of the VMS, which was designed to enhance motorist communication and improve motorist safety within the corridor, was significantly limited. In particular, the availability of procedural guidelines for VMS operation would greatly facilitate future efforts to maximize measurable safety benefits to the system.

5.8. Summary

Within the Safe Passage project, a motorist communication system consisting of a VMS system, an HAR system, and a dedicated cellular phone system were implemented and integrated along a 30 mile section of I-90. The VMS system was evaluated in terms of both operational effectiveness and motorists opinions. Operational effectiveness of the VMS was reduced by its limited and inconsistent use. Motorist opinions were generally positive concerning the technology’s ability to provide current information and the enhanced conspicuity of the VMS, and also provided important feedback regarding the content and format of specific messages.

Future use of the system would be improved through staff training and development of procedural guidelines.

6. RURAL TRAFFIC MANAGEMENT CENTER

6.1. Background

Expansive travel distances and limited management personnel and resources seriously challenge effective traffic management in rural areas. In Montana, rapidly changing, severe weather conditions and mountainous terrain often exacerbate the situation. The study corridor often experiences heavy snow and ice formation during the winter months, with travelers facing high winds and the possibility of wildlife on the roadway at any time throughout the year. The sudden onset of adverse travel conditions, either weather or incident related, necessitates effective coordination and communication between a variety of response agencies, often involving more than one jurisdiction. Ultimately, the safety of the motoring public depends upon the accurate and timely dissemination of pertinent travel information, as well as the efficient response to hazardous conditions by maintenance personnel and emergency responders.

These concerns led to the formation of a Rural Traffic Management Center (RTMC) as part of the SAFE-PASSAGE project. The RTMC, which is housed at the MDT Maintenance Office in Bozeman, has three primary objectives: (1) to receive and process all incoming traffic related information; (2) to contact and request emergency response personnel; and (3) to disseminate real-time travel information to the public through a variety of mediums. The integrated nature of the system is believed to maximize the effectiveness of emergency response to hazardous conditions, and allows essential information to be quickly and accurately conveyed to travelers. The entire SAFE-PASSAGE motorist communication system, described in the previous chapter, is under the control and operation of the RMTC. For additional information regarding the rationale for and historical development of traffic management centers, the reader is referred to the first and second year reports (6, 7).

6.2. First Year Activity

Three major tasks were accomplished during the first year of the project: (1) existing and desired information flows through the RTMC were established; (2) equipment needs of the Center were mapped; and (3) the process of developing formal operating protocol was initiated. Information gathered from personal interviews with MDT Maintenance Office personnel in Bozeman was supplemented with responses from a brief questionnaire distributed to emergency response and public information agencies in the area to determine information flows and equipment needs. For more detailed information on first year activities related to RTMC, the reader is referred to the first year report (6).

6.3. Second Year Activity

Two major activities regarding the development of the RTMC took place during the second year. First, a two-day National Highway Institute (NHI) Incident Management Course, sponsored by the Western Transportation Institute, was conducted to discuss topics related to improvements in field operations. Invited participants included supervisory personnel from agencies that respond to or provide direct support for incident response on I-90 between Bozeman and Livingston. Valuable information was obtained for subsequent incorporation into the RTMC protocol regarding the strengths of and areas for improvement in current field operations. Second, a draft RTMS Operations Manual was prepared and later revised, based on comments received from

MDT reviewers. The reader is referred to the second year report for additional information and explanation of the activities related to the RTMC during the second year of the project (7).

6.4. Third Year Activity

Third year activities for the RTMC included the following activities: (1) finalizing the electronic templates for information dissemination and (2) identifying the weather characteristics most detrimental to traffic safety using statistical modeling methods.

The electronic templates were created to lend consistency to the information-sharing process and to streamline information-sharing activities for the RTMC personnel. The templates were created in Microsoft Access because of its ability to create forms that require minimal typing, to automatically parse information into customized reports, and to automatically create a historical database. Researchers modified the preliminary templates designed in the second year to: (1) align with the VMS messaging sets for consistency, (2) automatically suggest appropriate VMS and HAR messaging from the input screen, and (3) combine the construction and maintenance templates into a single template. MDT dispatchers initially tested the Access templates, but these templates were never operationally implemented.

The statistical model was developed to determine the environmental conditions that were most detrimental to safety. The end result of the model was the determination that only two environmental conditions were significant: (1) average wind speed and (2) roadway surface condition-damp. As wind speed increased, the likelihood of a severe crash decreased, while when the roadway surface condition was damp, the likelihood of a severe crash increased. For more information regarding the third year activities, the reader is referred to the third year report of this project (8).

6.5. Fourth Year Activity

A variety of tools were developed over the course of this project, including an operations manual and electronic templates to provide assistance to MDT for incident management and improve agency response communication, coordination, and event documentation. However, it does not appear that these tools have been employed to an appreciable extent by MDT to more effectively and efficiently manage roadway incidents within the SAFE-PASSAGE corridor. WTI research staff met several times with MDT personnel to encourage them to use the Operations Manual and electronic templates and to further explain the potential benefits of the RTMC, but MDT has yet to demonstrate their willingness or ability to adopt the recommended procedures. Thus, the RTMC did not become operational during the four years since the SAFE-PASSAGE project began. The elimination of this key component of the project has serious implications in terms of the potential benefits of the SAFE-PASSAGE technologies, and on the evaluation results (9).

6.6. Final Year Activity

Within the fifth year of the project, the supervisor of the Bozeman MDT Maintenance Office transferred to a new position and was replaced. However, there has continued to be no effort to organize or establish any operational policy or procedures for the RTMC. Based upon research staff contacts and observations, incident notification, response procedures, and communications are essentially the same as before the SAFE-PASSAGE project was initiated.

6.7. Institutional Challenges

In order to coordinate the technology implemented within the SAFE-PASSAGE project, the research team encouraged, promoted, and provided the support framework to establish a Rural Traffic Management Center (RTMC). Efforts by DOTs in other states in this regard have been highly successful; however, as noted previously, this component of the SAFE-PASSAGE project was not a priority by MDT and no additional support for the Center was given to the Bozeman Maintenance Office. In that the RTMC was never formally instituted, it cannot be evaluated as to its impact on operations or safety.

6.8. Summary

Within the SAFE-PASSAGE project, WTI designed a Rural Traffic Management Center (RTMC) for MDT that would meet the following objectives: (1) to receive and process all incoming traffic related information; (2) to contact and request emergency response personnel; and (3) to disseminate real-time travel information to the public through a variety of mediums. A variety of tools were developed over the course of this project, including an operations manual and electronic templates to provide assistance to MDT for incident management and improve agency response communication, coordination, and event documentation.

Although the framework for the RTMC was completed and available, MDT has not yet made the center operational. Full implementation of the RTMC in the future would allow for an evaluation of its effectiveness.

7. EVALUATION OF MEASURES OF EFFECTIVENESS

7.1. Overview

As discussed in the SAFE-PASSAGE first year report (6), and updated in the third year report, Measures of Effectiveness (MOEs) were selected to evaluate the project's success at meeting its stated goal and objectives: to enhance safety and improve operational efficiency within the SAFE-PASSAGE corridor. Included in this chapter is a comparison of the MOEs from the before period (January 1996 through February 2001) to the after period (March 2001 through December 2002). In addition to a direct comparison using descriptive statistics, a two-sample test was used to determine if there was a significant change in the number of accidents in several different categories. A general assumption of unequal variances was assumed because the after period has a variance of zero, having only one data point. The t-statistic for the t-test is:

$$t = \frac{\overline{x_1} - \overline{x_2}}{\sqrt{\frac{s_1^{\ 2}}{n_1} + \frac{s_2^{\ 2}}{n_2}}}$$

Where: x_1 is the mean during the before period
x_2 is the mean during the after period
n_1 is the size of the before period sample
n_2 is the size of the after period sample
$s_1^{\ 2}$ is the variance of the before period sample
$s_2^{\ 2}$ is the variance of the after period sample

A 90 percent confidence level was used to accept or refute the null hypothesis in each case.

7.2. Historical Data

The Montana Department of Transportation provided historical data on weather, road maintenance activities, traffic volumes, and vehicle crashes within the SAFE-PASSAGE corridor. These data provide pertinent baseline (i.e., before) measurements that describe travel and weather patterns along the designated stretch of I-90, as well as the maintenance and accident history of the study site. Before/after comparisons to evaluate project effectiveness utilize these historical data, along with comparable data collected following the implementation of the SAFE-PASSAGE technologies.

7.3. Crash Analyses

Motor vehicle crash data for the corridor were provided by the Montana Department of Transportation for the period January 1996 through December 2002 (11). The information was taken directly from crash reports completed by the law enforcement officers who investigated each crash. The Crash Location and Analysis Report includes the following information: location, time of day, date, day of week, road alignment, weather conditions, road conditions, light conditions, property damage, injuries, and contributing circumstances. It should be noted that, although law enforcement officers receive some training as to the proper completion of these reports, there is a certain amount of subjectivity involved in the process. For purposes of this study, the crash record for each crash was reviewed and an assessment made regarding the effect weather may have had on the accident, as discussed below.

An active weather system can have profound effects on vehicular travel, including reduced visibility, dangerous crosswinds, and reduced traction. Crashes that occurred during these conditions were categorized as directly weather-related for subsequent analysis. After a storm passes, road conditions tend to fluctuate as freeze-thaw cycles occur. These cycles can often, and quite rapidly, result in such hazards as black ice. Crashes that took place under these conditions were classified as consequently weather-related. Other crashes may have occurred as a result of various, non-weather-related factors. These crashes were categorized as not weather-related for purpose of analysis.

The data collected for each year were first sorted according to the reported weather conditions at the time of the crash. Table 2 shows the reported weather condition at the time of the crash and the frequency of each reported weather type for all crashes before and after the implementation of SAFE-PASSAGE technologies. Snow and Cloudy were the two predominant weather conditions noted at the time of the crashes. Crosswinds, which are common in the study area, were reported in 13 percent of the before period crashes and 7 percent of the after period crashes. Crosswinds were the only other significant weather condition reported during the study period. By comparison, clear conditions were reported over 25 percent of the time for crashes in both the before and after periods (29 percent and 25 percent, respectively). Statistically, there was no difference in the reported weather conditions between the two periods of the analysis.

The data subsequently were sorted as to the various road conditions reported at the time of the crashes (Table 3). The findings illustrate that the road conditions were compromised (i.e., icy, snowy, or wet) for approximately 60 percent of the reported crashes. Dry conditions, on the other hand, existed for the remaining 40 percent of the crashes. As with reported weather conditions, the reported road conditions were found to be statistically equivalent for the before and after periods.

Table 2: Reported Weather Conditions for Crashes Before an After SAFE-PASSAGE Implementation

	Total Before (Jan 1996-Feb 2001)	Percent Before	Mar-Dec 2001	2002	Total After	Percent After
Clear	211	29.1%	30	35	65	24.7%
Cloudy	171	23.6%	35	48	83	31.6%
Rain	18	2.5%	1	2	3	1.1%
Snow	194	26.8%	26	60	86	32.7%
Sleet	19	2.6%	0	3	3	1.1%
Fog	5	0.7%	1	2	3	1.1%
X-Winds	94	13.0%	12	7	19	7.2%
N/A	13	1.8%	0	1	1	0.4%
Total	725	100.0%	105	158	263	100.0%

Table 3: Reported Road Conditions for Crashes Before and After SAFE-PASSAGE Implementation

	Total Before (Jan 1996-Feb 2001)	Percent Before	Mar-Dec 2001	2002	Total After	Percent After
Dry	286	39.4%	52	53	105	39.9%
Ice	272	37.5%	32	69	101	38.4%
Snow/Slush	128	17.7%	14	26	40	15.2%
Wet	38	5.2%	6	9	15	5.7%
N/A	1	0.1%	1	1	2	0.8%
Total	725	100.0%	105	158	263	100.0%

As discussed previously in this chapter, each crash in the database was examined individually to determine what, if any, role was played by weather in the crash. Weather condition was found to be directly related to approximately 25 percent of the crashes that occurred in the corridor over the designated time period (Table 4). In other words, close to one-fourth of the crashes took place during active weather systems that adversely affected travel conditions. When consequential weather-related crashes were included, weather was determined to have been a contributing factor in roughly 60 percent of all crashes. These data, combined with data presented in the previous two tables, indicate that weather-related crashes have not changed significantly following the implementation of SAFE-PASSAGE technologies.

Table 4: Consequential Relationship of Weather to Crashes Before and After SAFE-PASSAGE Implementation

	Total Before (Jan 1996-Feb 2001)	Percent Before	Mar-Dec 2001	2002	Total After	Percent After
Direct	179	24.7%	22	29	51	19.4%
Consequential	247	34.1%	29	78	107	40.7%
Not Related	299	41.2%	54	51	105	39.9%
Total	725	100.0%	105	158	263	100.0%

No statistical difference was found between the before and after periods when the consequential relationship of weather to crashes was analyzed. Although the frequency of weather-related crashes was not reduced by a statistically significant amount, there was a shift in the severity of crashes that occurred in the study corridor, as shown in Table 5. Specifically, the percentage of injury crashes declined from the before to the after period, with a corresponding increase in the percentage of PDO crashes. This reduction in crash severity could suggest that motorists drove more cautiously after the implementation of SAFE-PASSAGE technologies, perhaps in response to VMS messages regarding compromised road or weather conditions. This, in turn, could have resulted in crashes with less extensive damage or less severe injuries. However, using the two-sample t-test on the number of injury crashes, the apparent shift in crash severity following VMS implementation was not found to be statistically significant at the 90 percent confidence level.

Table 5: Severity of Crashes Before and After SAFE-PASSAGE Implementation

	Total Before (Jan 1996-Feb 2001)	Percent Before	Mar-Dec 2001	2002	Total After	Percent After
Fatality	12	1.7%	1	3	4	1.5%
PDO	494	68.1%	84	106	190	72.2%
Injury	219	30.2%	20	49	69	26.2%
Total	725	100.0%	105	158	263	100.0%

Figure 4 illustrates the total crash distribution by mile marker for the period 1996-2002. These data, when used in conjunction with data presented in other tables to follow, identifies high crash locations in the SAFE-PASSAGE corridor, both in terms of total crashes (Figure 4) and crashes that occurred during various adverse weather or road conditions (Tables 6-10).

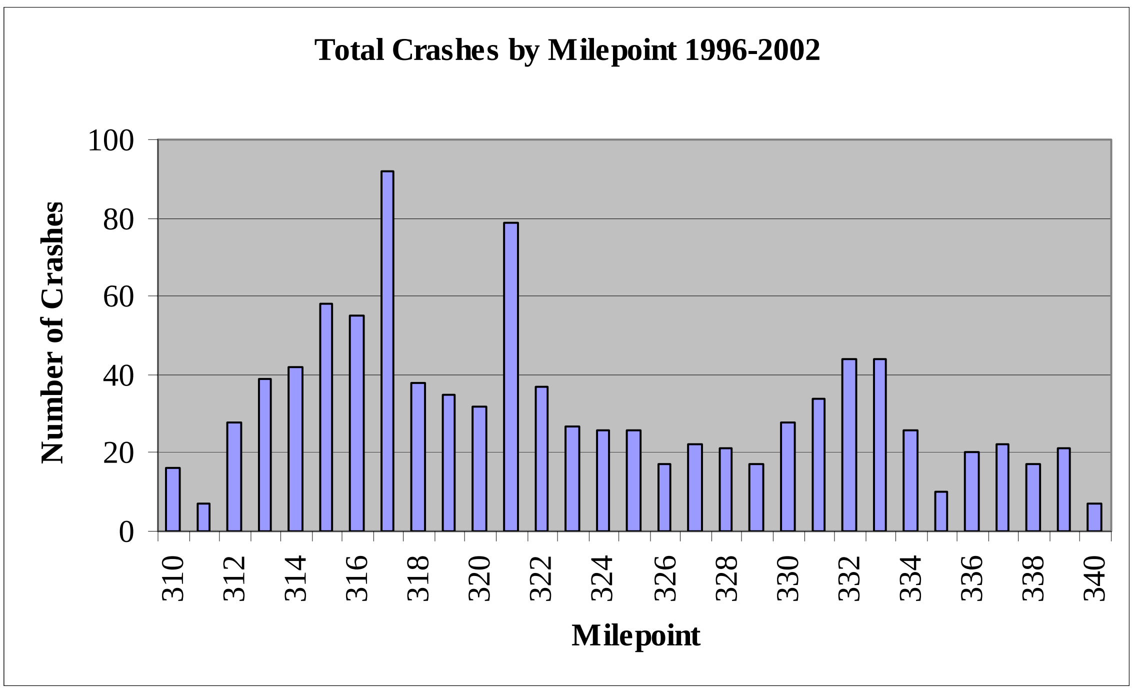

Figure 4: Total Crashes by Milepoint 1996-2002

Table 6 illustrates weather-related crashes through the corridor broken down by mile marker. The calculated percentages of weather-related accidents over the six-year period (1996-2002) indicate that Mile Markers 324, 326, and 331 experienced the highest frequencies of adverse weather-related crashes. Over 70 percent of the before crashes at each of these mile markers, as well as at Mile Markers 313, 316, 321, and 334, were reportedly weather-related. During the after period, a very similar pattern was seen.

Table 6: Weather Related Crashes by Mile Marker and Year

	Total Before (Jan 1996-Feb 2000)			Mar-Dec 2001			2002			Total After		
Mile Marker	**Total Crashes**	**WR Crashes**	**WR Percentage**	**Total Crashes**	**WR Crashes**	**WR Percentage**	**Total Crashes**	**WR Crashes**	**WR Percentage**	**Total Crashes**	**WR Crashes**	**WR Percentage**
310.0-310.9	8	2	25.0%	5	1	20.0%	3	0	0.0%	8	1	12.5%
311.0-311.9	5	2	40.0%	2	1	50.0%	0	0	-	2	1	50.0%
312.0-312.9	18	11	61.1%	3	0	0.0%	7	1	14.3%	10	1	10.0%
313.0-313.9	24	17	70.8%	4	2	50.0%	11	7	63.6%	15	9	60.0%
314.0-314.9	29	15	51.7%	5	2	40.0%	8	4	50.0%	13	6	46.2%
315.0-315.9	43	29	67.4%	2	1	50.0%	13	10	76.9%	15	11	73.3%
316.0-316.9	37	27	73.0%	10	7	70.0%	8	7	87.5%	18	14	77.8%
317.0-317.9	72	34	47.2%	7	2	28.6%	13	9	69.2%	20	11	55.0%
318.0-318.9	25	15	60.0%	4	2	50.0%	9	9	100.0%	13	11	84.6%
319.0-319.9	26	16	61.5%	4	2	50.0%	5	4	80.0%	9	6	66.7%
320.0-320.9	27	18	66.7%	1	1	100.0%	4	3	75.0%	5	4	80.0%
321.0-321.9	58	42	72.4%	11	8	72.7%	10	6	60.0%	21	14	66.7%
322.0-322.9	30	14	46.7%	1	1	100.0%	6	5	83.3%	7	6	85.7%
323.0-323.9	17	7	41.2%	8	3	37.5%	2	2	100.0%	10	5	50.0%
324.0-324.9	16	12	75.0%	3	2	66.7%	7	6	85.7%	10	8	80.0%
325.0-325.9	18	11	61.1%	5	2	40.0%	3	2	66.7%	8	4	50.0%
326.0-326.9	16	13	81.3%	0	0	-	1	1	100.0%	1	1	100.0%
327.0-327.9	16	6	37.5%	3	0	0.0%	3	2	66.7%	6	2	33.3%
328.0-328.9	18	11	61.1%	1	1	100.0%	2	0	0.0%	3	1	33.3%
329.0-329.9	15	10	66.7%	0	0	-	2	1	50.0%	2	1	50.0%
330.0-330.9	20	10	50.0%	1	0	0.0%	7	5	71.4%	8	5	62.5%
331.0-331.9	22	18	81.8%	6	4	66.7%	6	6	100.0%	12	10	83.3%
332.0-332.9	29	15	51.7%	9	4	44.4%	6	4	66.7%	15	8	53.3%
333.0-333.9	36	18	50.0%	4	3	75.0%	4	4	100.0%	8	7	87.5%
334.0-334.9	21	16	76.2%	0	0	-	5	3	60.0%	5	3	60.0%
335.0-335.9	8	2	25.0%	2	0	0.0%	0	0	-	2	0	0.0%
336.0-336.9	19	11	57.9%	0	0	-	1	1	100.0%	1	1	100.0%
337.0-337.9	15	4	26.7%	3	2	66.7%	4	1	25.0%	7	3	42.9%
338.0-338.9	12	7	58.3%	0	0	-	5	2	40.0%	5	2	40.0%
339.0-339.9	17	9	52.9%	1	0	0.0%	3	2	66.7%	4	2	50.0%
340.0-340.9	7	3	42.9%	0	0	-	0	0	-	0	0	-
TOTAL	724	425	58.7%	105	51	48.6%	158	107	67.7%	263	158	60.1%

However, there was no statistically significant difference in weather-related accidents at each location between the before and after periods at the 90 percent confidence level.

Within the historical crash data, crosswinds were identified as a predominant weather condition at the time of the crash. High winds can cause motor vehicle operators to lose control of their vehicles, resulting in crashes. Wind can have adverse effects on visibility, as well, which can contribute to crashes. The annual distributions of wind-related crashes are presented in Table 7. Although not statistically significant, the number of wind-related crashes has declined from an average of 27 per year before SAFE-PASSAGE system installation to 10 per year in the period after the VMS were installed. Wind advisories were commonly displayed on the VMS; therefore, it is possible that this reduction was due, at least in part, to drivers being made aware of high winds and modifying their driving behavior accordingly.

Snowstorms can have a profound impact on traveler safety in the SAFE-PASSAGE corridor, also. The crash data was sorted to identify where crashes occurred most often in the corridor during snowstorms. Yearly breakdowns of crashes during snowstorms and their location by mile marker are presented in Table 8. The distributions of snowstorm-related crashes by mile marker were similar during the before and after periods. The number of snowstorm-related crashes was reduced in the after period, and this reduction was found to be statistically significant at a 90 percent confidence level.

The intuitively obvious correlation between weather and road condition means that, as with weather, road surface condition can have an enormous impact on the safety of travel in the SAFE-PASSAGE corridor. Many of the crashes that occurred along the designated stretch of I-90 were attributed to snow or ice on the road surface. The annual numbers of crashes in the corridor that occurred when ice or snow was present on the road surface are displayed by mile marker in Table 9 and Table 10, respectively. In terms of overall crashes, there was no statistically significant change in the number of crashes that occurred during icy road conditions following VMS implementation. However, there was a statistically significant reduction in post-VMS implementation crashes occurring during slush/snow road conditions at the 90 percent confidence level.

Another analysis was conducted to determine the relevancy of the VMS message to the road and weather conditions reported during crashes. If the message on the sign warned of a hazardous condition (i.e., road or weather related) that was reported to be a contributing factor to the crash, then the message was considered to be relevant. If the message did not display a warning of the hazard that contributed to the crash, or if no message was displayed on the sign, then the messages were considered not relevant. If the crash was caused by something for which an appropriate warning could not be displayed (i.e., driver error or mechanical failure), the message was considered neutral. Table 11 provides a breakdown of the relevancy of the VMS message for each crash. The data show that the message on the sign was relevant to the contributing factor(s) to the crash only 32 percent of the time.

Table 7: Wind-Related Crashes by Mile Marker and Year

	Total Before (Jan 1996-Feb 2000)			Mar-Dec 2001			2002			Total After		
Mile Marker	**Total Crashes**	**WR Crashes**	**WR Percentage**	**Total Crashes**	**WR Crashes**	**WR Percentage**	**Total Crashes**	**WR Crashes**	**WR Percentage**	**Total Crashes**	**WR Crashes**	**WR Percentage**
310.0-310.9	8	0	0.0%	5	0	0.0%	3	0	0.0%	8	0	0.0%
311.0-311.9	5	0	0.0%	2	0	0.0%	0	0	-	2	0	0.0%
312.0-312.9	18	2	11.1%	3	0	0.0%	7	0	0.0%	10	0	0.0%
313.0-313.9	24	0	0.0%	4	0	0.0%	11	0	0.0%	15	0	0.0%
314.0-314.9	29	4	13.8%	5	0	0.0%	8	0	0.0%	13	0	0.0%
315.0-315.9	43	2	4.7%	2	0	0.0%	13	0	0.0%	15	0	0.0%
316.0-316.9	37	2	5.4%	10	0	0.0%	8	0	0.0%	18	0	0.0%
317.0-317.9	72	3	4.2%	7	0	0.0%	13	0	0.0%	20	0	0.0%
318.0-318.9	25	2	8.0%	4	0	0.0%	9	0	0.0%	13	0	0.0%
319.0-319.9	26	4	15.4%	4	0	0.0%	5	0	0.0%	9	0	0.0%
320.0-320.9	27	9	33.3%	1	0	0.0%	4	0	0.0%	5	0	0.0%
321.0-321.9	58	14	24.1%	11	0	0.0%	10	0	0.0%	21	0	0.0%
322.0-322.9	30	2	6.7%	1	0	0.0%	6	0	0.0%	7	0	0.0%
323.0-323.9	17	0	0.0%	8	0	0.0%	2	0	0.0%	10	0	0.0%
324.0-324.9	16	2	12.5%	3	0	0.0%	7	0	0.0%	10	0	0.0%
325.0-325.9	18	3	16.7%	5	1	20.0%	3	0	0.0%	8	1	12.5%
326.0-326.9	16	3	18.8%	0	0	-	1	0	0.0%	1	0	0.0%
327.0-327.9	16	3	18.8%	3	0	0.0%	3	1	33.3%	6	1	16.7%
328.0-328.9	18	4	22.2%	1	0	0.0%	2	0	0.0%	3	0	0.0%
329.0-329.9	15	5	33.3%	0	0	-	2	0	0.0%	2	0	0.0%
330.0-330.9	20	7	35.0%	1	0	0.0%	7	1	14.3%	8	1	12.5%
331.0-331.9	22	19	86.4%	6	4	66.7%	6	5	83.3%	12	9	75.0%
332.0-332.9	29	7	24.1%	9	1	11.1%	6	1	16.7%	15	2	13.3%
333.0-333.9	36	12	33.3%	4	2	50.0%	4	1	25.0%	8	3	37.5%
334.0-334.9	21	14	66.7%	0	0	-	5	1	20.0%	5	1	20.0%
335.0-335.9	8	0	0.0%	2	0	0.0%	0	0	-	2	0	0.0%
336.0-336.9	19	5	26.3%	0	0	-	1	0	0.0%	1	0	0.0%
337.0-337.9	15	2	13.3%	3	0	0.0%	4	0	0.0%	7	0	0.0%
338.0-338.9	12	5	41.7%	0	0	-	5	0	0.0%	5	0	0.0%
339.0-339.9	17	4	23.5%	1	0	0.0%	3	0	0.0%	4	0	0.0%
340.0-340.9	7	0	0.0%	0	0	-	0	0	-	0	0	-
TOTAL	724	139	19.2%	105	8	7.6%	158	10	6.3%	263	18	6.8%

Table 8: Snowstorm-Related Crashes by Mile Marker and Year

	Total Before (Jan 1996-Feb 2000)			Mar-Dec 2001			2002			Total After		
Mile Marker	**Total Crashes**	**SR Crashes**	**SR Percentage**	**Total Crashes**	**SR Crashes**	**SR Percentage**	**Total Crashes**	**SR Crashes**	**SR Percentage**	**Total Crashes**	**SR Crashes**	**SR Percentage**
310.0-310.9	8	2	25.0%	5	1	20.0%	3	0	0.0%	8	1	12.5%
311.0-311.9	5	2	40.0%	2	1	50.0%	0	0	-	2	1	50.0%
312.0-312.9	18	5	27.8%	3	0	0.0%	7	0	0.0%	10	0	0.0%
313.0-313.9	24	7	29.2%	4	3	75.0%	11	2	18.2%	15	5	33.3%
314.0-314.9	29	12	41.4%	5	2	40.0%	8	0	0.0%	13	2	15.4%
315.0-315.9	43	11	25.6%	2	0	0.0%	13	1	7.7%	15	0	0.0%
316.0-316.9	37	17	45.9%	10	4	40.0%	8	0	0.0%	18	4	22.2%
317.0-317.9	72	19	26.4%	7	5	71.4%	13	1	7.7%	20	6	30.0%
318.0-318.9	25	12	48.0%	4	1	25.0%	9	2	22.2%	13	3	23.1%
319.0-319.9	26	6	23.1%	4	2	50.0%	5	2	40.0%	9	4	44.4%
320.0-320.9	27	9	33.3%	1	1	100.0%	4	0	0.0%	5	1	20.0%
321.0-321.9	58	20	34.5%	11	4	36.4%	10	2	20.0%	21	6	28.6%
322.0-322.9	30	7	23.3%	1	0	0.0%	6	0	0.0%	7	0	0.0%
323.0-323.9	17	6	35.3%	8	3	37.5%	2	1	50.0%	10	4	40.0%
324.0-324.9	16	8	50.0%	3	1	33.3%	7	0	0.0%	10	1	10.0%
325.0-325.9	18	10	55.6%	5	3	60.0%	3	0	0.0%	8	3	37.5%
326.0-326.9	16	6	37.5%	0	0	-	1	0	0.0%	1	0	0.0%
327.0-327.9	16	5	31.3%	3	0	0.0%	3	1	33.3%	6	1	16.7%
328.0-328.9	18	7	38.9%	1	1	100.0%	2	0	0.0%	3	1	33.3%
329.0-329.9	15	3	20.0%	0	0	-	2	0	0.0%	2	0	0.0%
330.0-330.9	20	4	20.0%	1	0	0.0%	7	3	42.9%	8	3	37.5%
331.0-331.9	22	0	0.0%	6	0	0.0%	6	1	16.7%	12	1	8.3%
332.0-332.9	29	6	20.7%	9	2	22.2%	6	0	0.0%	15	2	13.3%
333.0-333.9	36	6	16.7%	4	1	25.0%	4	0	0.0%	8	1	12.5%
334.0-334.9	21	4	19.0%	0	0	-	5	0	0.0%	5	0	0.0%
335.0-335.9	8	0	0.0%	2	0	0.0%	0	0	-	2	0	0.0%
336.0-336.9	19	7	36.8%	0	0	-	1	0	0.0%	1	0	0.0%
337.0-337.9	15	3	20.0%	3	0	0.0%	4	0	0.0%	7	0	0.0%
338.0-338.9	12	2	16.7%	0	0	-	5	0	0.0%	5	0	0.0%
339.0-339.9	17	0	0.0%	1	1	100.0%	3	1	33.3%	4	2	50.0%
340.0-340.9	7	1	14.3%	0	0	-	0	0	-	0	0	-
TOTAL	724	207	28.6%	105	36	34.3%	158	17	10.8%	263	52	19.8%

Table 9: Road Condition- Related Crashes by Mile Marker and Year

	Total Before (Jan 1996-Feb 2000)			Mar-Dec 2001			2002			Total After		
Mile Marker	**Total Crashes**	**IR Crashes**	**IR Percentage**	**Total Crashes**	**IR Crashes**	**IR Percentage**	**Total Crashes**	**IR Crashes**	**IR Percentage**	**Total Crashes**	**IR Crashes**	**IR Percentage**
310.0-310.9	8	1	12.5%	5	0	0.0%	3	0	0.0%	8	0	0.0%
311.0-311.9	5	1	20.0%	2	0	0.0%	0	0	-	2	0	0.0%
312.0-312.9	18	7	38.9%	3	0	0.0%	7	0	0.0%	10	0	0.0%
313.0-313.9	24	13	54.2%	4	1	25.0%	11	5	45.5%	15	6	40.0%
314.0-314.9	29	6	20.7%	5	0	0.0%	8	3	37.5%	13	3	23.1%
315.0-315.9	43	18	41.9%	2	0	0.0%	13	10	76.9%	15	0	0.0%
316.0-316.9	37	25	67.6%	10	6	60.0%	8	6	75.0%	18	12	66.7%
317.0-317.9	72	25	34.7%	7	4	57.1%	13	7	53.8%	20	11	55.0%
318.0-318.9	25	9	36.0%	4	1	25.0%	9	7	77.8%	13	8	61.5%
319.0-319.9	26	8	30.8%	4	3	75.0%	5	4	80.0%	9	7	77.8%
320.0-320.9	27	11	40.7%	1	0	0.0%	4	2	50.0%	5	2	40.0%
321.0-321.9	58	26	44.8%	11	5	45.5%	10	6	60.0%	21	11	52.4%
322.0-322.9	30	9	30.0%	1	1	100.0%	6	4	66.7%	7	5	71.4%
323.0-323.9	17	4	23.5%	8	0	0.0%	2	2	100.0%	10	2	20.0%
324.0-324.9	16	11	68.8%	3	3	100.0%	7	6	85.7%	10	9	90.0%
325.0-325.9	18	8	44.4%	5	0	0.0%	3	1	33.3%	8	1	12.5%
326.0-326.9	16	7	43.8%	0	0	-	1	0	0.0%	1	0	0.0%
327.0-327.9	16	4	25.0%	3	0	0.0%	3	1	33.3%	6	1	16.7%
328.0-328.9	18	6	33.3%	1	1	100.0%	2	0	0.0%	3	1	33.3%
329.0-329.9	15	9	60.0%	0	0	-	2	0	0.0%	2	0	0.0%
330.0-330.9	20	4	20.0%	1	0	0.0%	7	3	42.9%	8	3	37.5%
331.0-331.9	22	5	22.7%	6	0	0.0%	6	2	33.3%	12	2	16.7%
332.0-332.9	29	12	41.4%	9	2	22.2%	6	2	33.3%	15	4	26.7%
333.0-333.9	36	6	16.7%	4	0	0.0%	4	3	75.0%	8	3	37.5%
334.0-334.9	21	10	47.6%	0	0	-	5	2	40.0%	5	2	40.0%
335.0-335.9	8	2	25.0%	2	0	0.0%	0	0	-	2	0	0.0%
336.0-336.9	19	5	26.3%	0	0	-	1	1	100.0%	1	1	100.0%
337.0-337.9	15	4	26.7%	3	2	66.7%	4	1	25.0%	7	3	42.9%
338.0-338.9	12	5	41.7%	0	0	-	5	0	0.0%	5	0	0.0%
339.0-339.9	17	9	52.9%	1	0	0.0%	3	0	0.0%	4	0	0.0%
340.0-340.9	7	3	42.9%	0	0	-	0	0	-	0	0	-
TOTAL	724	273	37.7%	105	29	27.6%	158	78	49.4%	263	97	36.9%

Table 10: Snow/Slush Road Condition Related Crashes by Mile Marker and Year

	Total Before (Jan 1996-Feb 2000)			Mar-Dec 2001			2002			Total After		
Mile Marker	Total Crashes	SSR Crashes	SSR Percentage	Total Crashes	SSR Crashes	SSR Percentage	Total Crashes	SSR Crashes	SSR Percentage	Total Crashes	SSR Crashes	SSR Percentage
310.0-310.9	8	1	12.5%	5	1	20.0%	3	0	0.0%	8	1	12.5%
311.0-311.9	5	1	20.0%	2	1	50.0%	0	0	-	2	1	50.0%
312.0-312.9	18	1	5.6%	3	0	0.0%	7	0	0.0%	10	0	0.0%
313.0-313.9	24	1	4.2%	4	0	0.0%	11	3	27.3%	15	3	20.0%
314.0-314.9	29	8	27.6%	5	2	40.0%	8	1	12.5%	13	3	23.1%
315.0-315.9	43	6	14.0%	2	1	50.0%	13	1	7.7%	15	0	0.0%
316.0-316.9	37	3	8.1%	10	1	10.0%	8	2	25.0%	18	3	16.7%
317.0-317.9	72	6	8.3%	7	2	28.6%	13	3	23.1%	20	5	25.0%
318.0-318.9	25	6	24.0%	4	1	25.0%	9	2	22.2%	13	3	23.1%
319.0-319.9	26	5	19.2%	4	0	0.0%	5	0	0.0%	9	0	0.0%
320.0-320.9	27	12	44.4%	1	0	0.0%	4	1	25.0%	5	1	20.0%
321.0-321.9	58	18	31.0%	11	1	9.1%	10	0	0.0%	21	1	4.8%
322.0-322.9	30	3	10.0%	1	0	0.0%	6	1	16.7%	7	1	14.3%
323.0-323.9	17	4	23.5%	8	3	37.5%	2	0	0.0%	10	3	30.0%
324.0-324.9	16	1	6.3%	3	0	0.0%	7	0	0.0%	10	0	0.0%
325.0-325.9	18	4	22.2%	5	0	0.0%	3	2	66.7%	8	2	25.0%
326.0-326.9	16	3	18.8%	0	0	-	1	1	100.0%	1	1	100.0%
327.0-327.9	16	3	18.8%	3	0	0.0%	3	0	0.0%	6	0	0.0%
328.0-328.9	18	2	11.1%	1	0	0.0%	2	0	0.0%	3	0	0.0%
329.0-329.9	15	5	33.3%	0	0	-	2	1	50.0%	2	1	50.0%
330.0-330.9	20	5	25.0%	1	0	0.0%	7	1	14.3%	8	1	12.5%
331.0-331.9	22	12	54.5%	6	0	0.0%	6	1	16.7%	12	1	8.3%
332.0-332.9	29	4	13.8%	9	0	0.0%	6	2	33.3%	15	2	13.3%
333.0-333.9	36	9	25.0%	4	1	25.0%	4	1	25.0%	8	2	25.0%
334.0-334.9	21	11	52.4%	0	0	-	5	1	20.0%	5	1	20.0%
335.0-335.9	8	0	0.0%	2	0	0.0%	0	0	-	2	0	0.0%
336.0-336.9	19	4	21.1%	0	0	-	1	1	100.0%	1	1	100.0%
337.0-337.9	15	1	6.7%	3	0	0.0%	4	1	25.0%	7	1	14.3%
338.0-338.9	12	4	33.3%	0	0	-	5	0	0.0%	5	0	0.0%
339.0-339.9	17	4	23.5%	1	0	0.0%	3	2	66.7%	4	2	50.0%
340.0-340.9	7	0	0.0%	0	0	-	0	0	-	0	0	-
TOTAL	724	147	20.3%	105	14	13.3%	158	28	17.7%	263	40	15.2%

Table 11: Relevancy of VMS Messages to Conditions Contributing to Crashes

	Mar-Dec 2001	2002	Total	Percent
Neutral	52	50	102	38.8%
Relevant	33	51	84	31.9%
Not Relevant	20	57	77	29.3%
Total	105	158	263	100.0%

One of the objectives of the VMS is to warn other drivers of an accident that has occurred ahead of them on the roadway to help prevent secondary collisions. To determine the effectiveness of the technology at reducing such crashes, the number of secondary accidents that occurred during the before and after periods were compared. Four years of accident data were included in the analysis (1999-2002). A secondary accident was defined as one that occurred within one mile and within one hour of a previous crash. The average number of secondary accidents before the motorist communication system became operational was 5.85 per year, as shown in Table 12. After the system was implemented, the average increased to 9.50 secondary accidents per year. Although this finding was counterintuitive, the low frequencies of secondary accidents must be taken into consideration when interpreting these results. Moreover, it was noted previously in this document that an accident message was displayed on the variable message signs only six times during the year following the VMS implementation date, despite the fact that 134 crashes occurred during that period in the study corridor.

Table 12: Annual Frequencies of Secondary Crashes

Year	Secondary Crashes	Total Crashes	Percent Secondary
1999	4	140	2.9%
2000	10	132	7.6%
Jan-Feb 2001	3	19	15.8%
Total Before	17	291	5.8%
Mar-Dec 2001	6	105	5.7%
2002	19	158	12.0%
Total After	25	263	9.5%

7.4. Institutional Challenges

Difficulties associated with MDT's under-utilization of the weather model, ineffective VMS operations, and failure to implement the RTMC were discussed elsewhere in this report. Any or all of these factors may have contributed to the fact that there were no statistically significant reductions in crashes within the SAFE-PASSAGE corridor following system implementation. While such correlations may have intuitive appeal, their impact on the potential effectiveness of the SAFE-PASSAGE project cannot be measured in any meaningful way.

It also must be acknowledged that the after period of analysis (i.e., 22 months) is extremely limited, given the inherent instability of motor vehicle crash data. Moreover, annual variations in temperature, precipitation, and other environmental conditions could severely impact the results of this analysis. At this time, therefore, it is difficult to make a determination whether the safety benefits of the ITS technology deployed for the SAFE-PASSAGE project justify the WTI expenditures for equipment and manpower.

7.5. Summary

The project team attempted to evaluate the effectiveness of the SAFE-PASSAGE project by analyzing crash data from both before and after project implementation. Various factors were identified and taken into consideration for the analysis, including road condition at the time of each crash, weather conditions, relationship of weather to crash, severity of crash, exact location (mile marker) and relevancy of VMS message to conditions contributing to crash.

This analysis did not show any significant reduction in crashes after system implementation. However, the limited effectiveness may have been influenced by the fact that not all components of the projects were fully realized. Further analysis would be warranted in the future if MDT fully implements more components of the project, or as more crash data becomes available.

8. CONCLUSIONS AND RECOMMENDATIONS

In summary, the objectives of this project were to: (1) develop and validate a pavement temperature prediction model; (2) implement a motorist communication system; and (3) institute a rural traffic management center. The extent to which these objectives were met was to be evaluated using accident reduction as the primary, quantitative measure of effectiveness. Motorist perceptions obtained by field surveys were to be used as a secondary, qualitative measure of effectiveness. The following conclusions and recommendations are provided.

8.1. Conclusions

The project was originally scheduled as a three-year study with all elements to be operational after one year. This time frame was overly ambitious, and the Montana Department of Transportation (MDT) needed more time for both contracting and field installation. As a result, the system was not operational until March 2001, more than two years into the project. Almost two full years of post (i.e., after period) crash data were available for pre/post (i.e., before/after) comparisons. Although this limited analysis indicated a slight reduction in annual total accidents in the 22-month period after system implementation, compared to the annual average for five years before system implementation, the difference was not statistically significant. As with any accident data analysis, however, results should be considered statistically marginal with only two years of post-treatment data available for comparison.

Validation results for the pavement temperature prediction model were indicated favorable and enhancements are continuing. Within the last two years, output from the model was available to the Montana Department of Transportation via an accessible web site. Forecast information for the project corridor could be monitored with real-time updates. Due to manpower limitations within the Bozeman Maintenance Office, MDT has not, as of this date, utilized the model either for advanced motorist warnings of changing environmental conditions or to aid in decisions regarding resource deployment for winter maintenance.

Utilization of the motorist communication system associated with SAFE-PASSAGE has been less than favorable. Messages displayed on the variable message signs (VMS) have been inconsistent, untimely, and many times inappropriate. Most motorists who were surveyed acknowledged the technology's potential usefulness and effectiveness, but many also criticized the content and format of the messages themselves. Message format and display have not followed national guidelines. Many messages were found to be too lengthy to be read in the available time, based upon posted highway speeds. No operational staff has been assigned to the task of VMS messaging, and those MDT staff members responsible for VMS operation are untrained in human factors concepts relevant to dynamic motorist communication.

In addition, no significant hardware upgrades to the Highway Advisory Radio (HAR) system were ever made, although this had been planned by MDT. Likewise, no significant operational changes to HAR message broadcasts or operational procedures were made during the project period. A closed-circuit camera was installed within the designated study site; however, the purpose for and extent to which this equipment was utilized are unknown.

Survey results from both familiar and unfamiliar motorists emphasized the importance of advanced weather and road condition information for safe travel, as well as recognition of dynamic message signs as a viable tool for timely communication of relevant information.

Survey results also indicated, however, that motorists have no patience with displays of what they perceive as irrelevant information via expensive technology. In addition, motorists do not appreciate untimely messages or ones they interpret as inappropriate.

In spite of the support and stated cooperation by law enforcement and emergency response providers, the Rural Traffic Management Center, planned as the focal point for reception and dissemination of incident communications and control, was never made operational by MDT. No staff commitment was made nor was computer software to facilitate the coordination of resources ever utilized.

In summary, numerous Intelligent Transportation System technologies were developed, tested, and deployed in a rural 30-mile Interstate highway corridor to address traveler safety challenges caused by weather-related road conditions. Quantitatively, no statistically significant reductions in crashes could be determined with the limited availability of comparative, post-implementation data. Qualitatively, the perceived benefits of the motorist communication system by drivers who responded to the roadside survey were mixed. Neither of these findings resulted from problems with the application utility or potential effectiveness of either the motorist communication system or the pavement temperature prediction model. Rather, the results are inconclusive and/or less than satisfactory due to institutional problems. However further evaluation of the potential benefits may be warranted following any future implementation of the recommendations below.

8.2. Recommendations

The following recommendations are provided to improve the effectiveness of the Safe Passage System.

The pavement temperature prediction model website contains valuable information that may facilitate more effective motorist advisement and winter maintenance. Access and efficiently utilize the available web site information concerning environmental and pavement forecast conditions. Establish staff responsibility and procedures to fully utilize this technology;

Expanded and improved use of the motorist communication system could improve its effectiveness and resulting safety benefits. Develop and implement operational guidelines for the motorist communication system so that message displays and radio transmissions are (a) consistent, timely, and appropriate for incident conditions; and (b) in compliance with accepted national protocol regarding conspicuity, readability, and comprehension in order to obtain safe and proper responses by motorists;

Implementation of the Rural Traffic Management Center holds great potential as a focal point for incident response. Implement and support the Rural Traffic Management Center to receive and coordinate incident communications. Establish communications procedures to receive timely notice of incidents and to effectively warn approaching motorists. Commit and train staff to fully utilize available computer software; and continue to monitor crashes within the SAFE-PASSAGE corridor to build a post-implementation database to enable more reliable statistical conclusions about the safety benefits of the system. Also, continue to document motorist communication (i.e., message content, timing, and so forth) conveyed via variable message signs and/or highway advisory radio in order to improve the performance of the communication system and to enhance motorist perception of the effectiveness of the technology.

9. APPENDIX A: BOZEMAN PASS PAVEMENT TEMPERATURE FORECAST MODEL EVALUATION

Forecast Evaluations using Met-Data

For the evaluations that follow, small model was made of the stretch of highway neighboring the RWIS station at the top of Bozeman Hill (Bozeman Pass). The diurnal "core" temperature in the model was updated on a daily basis and each anaylsis was run over the period of 1 day (midnight to midnight). Using met data recorded by the RWIS station, the model was then run in a post-cast mode. This approach was used in order to evaluate the performance of the model with accurate input data.

Spring 2003: Met-Data Evaluations

In the first set of graphics will be discussed in some detail, with the intent of explaining to the reader what is displayed in each graph and what assumptions are built into the models used to generate the data.

A series of graphs were selected to demonstrate the performance the RadTherm/RTmodels. The first graph (e.g. Figure 1) displays a comparisons between forecast and measured temperatures, for the road surface. The second graph (Figure 2) display the difference between these temperatures.

The large difference displayed at the start of the week (Sunday morning) is due to initialization inaccuracy. Typically, initialization of one forecast is based on a previous forecast. At the start of each week, it was assumed that previous data did not exist, to evaluate the performance of the initialization routines. As a consequence, RadTherm/RT initialized the entire model based on incoming weather data and the diurnal core temperature, i.e., without surface temperature data. In these cases, the initialization is often inaccurate and it takes the model part of a day to "catch up". Most of the rest of the weeks forecast models take advantage of the ability to perform a "transient restart" from earlier forecasts.

The third figure (e.g. Figure 3) displays statistics that are based on the difference between the forecast and measured temperatures. In this case, Figure 3a illustrates the correlation between the forecast and measured air temperatures, where forecast temperatures are graphed against the measured temperatures. Data points are based on a smoothed local mean of the measure temperature at the corresponding to the time the forecast temperature was recorded. The solid line indicates what would be a perfect correlation. In other words, all data points would lie on this solid line if the forecast surface temperatures exactly matched measured surface temperatures. The model correlation coefficient (r_{mod}) provides a measure of the correlation with the measured data, i.e., the solid line. The model coefficient of determination (r^2_{mod}) expresses the proportion of variation in the measured data that is represented by the forecast. If y_i represents the forecast value and x_i represents the measured value, the coefficient of determination (r^2_{mod}) can be written as

$$r^2_{mod} = 1 - \frac{SSE_{mod}}{S_{xx}}, \tag{0.1}$$

where

$$S_{xx} = \sum_{i=1}^{n} (x_i - \bar{x})^2 \qquad \& \qquad SSE_{mod} = \sum_{i=1}^{n} (y_i - x_i)^2, \tag{0.2}$$

where SSE_{mod} is the sum of the squared error between the measured data and the forecast data.

The sample correlation coefficient (r_{fit}) provides a measure of the correlation between the data and the fitted regression (dashed) line while r^2_{fit} expresses the proportion of variation in the data that is represented by the linear fit. This coefficient of determination (r^2_{fit}) can be written as

$$r^2_{fit} = \frac{S^2_{xy}}{S_{yy}S_{xx}} \tag{0.3}$$

where

$$S_{yy} = \sum_{i=1}^{n} (y_i - \bar{y})^2 \qquad \& \qquad S_{xy} = \sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})\,. \tag{0.4}$$

The dashed line is included only to provide an estimate of "expected" values from the forecast model based on that weeks results. Comparing the two lines provides an estimate of the temperature dependence of the "expected" forecast temperature relative to the measured temperature. If there is no bias in the temperature forecasts, the dashed line should lie nearly on top of the solid line. To provide a qualitative measure of the differences between the expected forecast temperature and the measured temperature at the high and low extremes, two values are displayed in the lower right corner of the plot. First is the temperature difference between the highest measured temperature and the expected forecast value, based on the linear fit (dashed line), denoted by upper case (ΔT). Second is the temperature difference between the lowest measured temperature and the corresponding forecast value, again based on the dashed line, denoted by lower case (δT).

Figure 3c displays the residual or the difference between the forecast and measured temperature as a function of the measured temperature. In both of these graphs (Figure 3a & c), the data should be randomly distributed about the solid (red) line that passes through both graphs. If this is the case, then many of these differences can be attributed to fluctions in the weather that occur in a shorter time span that the model is set to track. If the points are not randomly distributed about the line, then the model has a bias that that may be due to an improperly set parameter or an error in the energy balance that the model is based on.

Similarly, Figure 3b and Figure 3d respectively display statistical measures of the differences in the measured vs. RadTherm/RT forecast surface temperatures. These statistical measures cannot be considered as measures of fit, but instead as displays of variation that may provide a measure of biases in the model behavior or as a measure of uncertainty in the forecast temperatures. Figure 3b displays a histogram based on data points used to compare the modeled and measured differences in temperature. On top of each histogram is a normal distribution, based on estimates of the sample mean and standard deviation for each data set. The intent of this overlap is to illustrate that the data points are not normally distributed. However, the distributions are considered close enough that the measures of mean and standard deviation are considered useful. The second sub-figure is used to display what are know as Q-Q normal plots. These plots display the difference between the quantiles of a normal distribution and the quantiles of the sample distribution. The horizontal axis is based on the theoretical normal distribution and assumes that the distribution has a mean of zero and a standard deviation of 1. If the sample distribution were well represented by a normal distribution, the sample points would be expected to lie very near the displayed line, which passes through the upper and lower quartiles ($\mu \pm \sigma$) of the sample and theoretical normal distributions. As displayed in these Q-Q plots, the sample distribution diverges from the line near the edges of the plot.

The fourth figure (e.g. Figure 4) shows the measured precipitation rate. Then the fifth figure (e.g. Figure 4) shows the estimated road condition based on responses from a sensor in the pavement next to the RWIS station. Road conditions with negative ID tags refer to non-dry conditions that occured while surface temperatures were below 0 $^\circ C$. Though the modeled results do partially take into account the effects due to precipitation rate (Figure 4) via mass influx, changes in albedo or emissivity due to snow or ice covering the road are not accounted for. RadTherm/RT does allow the user to interactively change the parameter settings, but it not yet smart enough to make these changes with out user interaction. Hence some of the forecast biases may be due to these non-varying parameters.

The sixth, seventh, and eighth figures (e.g. Figure 6, 7, and 8) repectively display variations in the incoming radiation, relative humidity, and wind speed. These meteorlogical data sets are all used as input in the model and are displayed primarily as an aid in evaluating and explaining variations in both the measured and forecast surface temperatures.

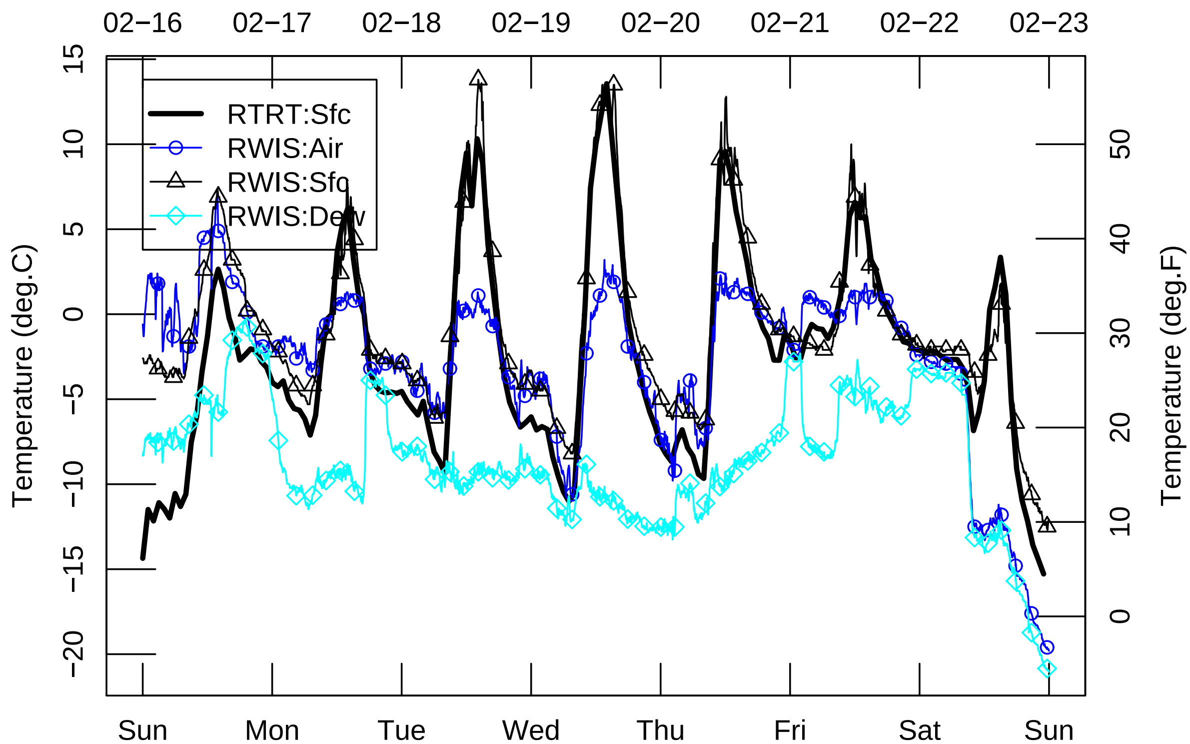

Figure 1: Temperature

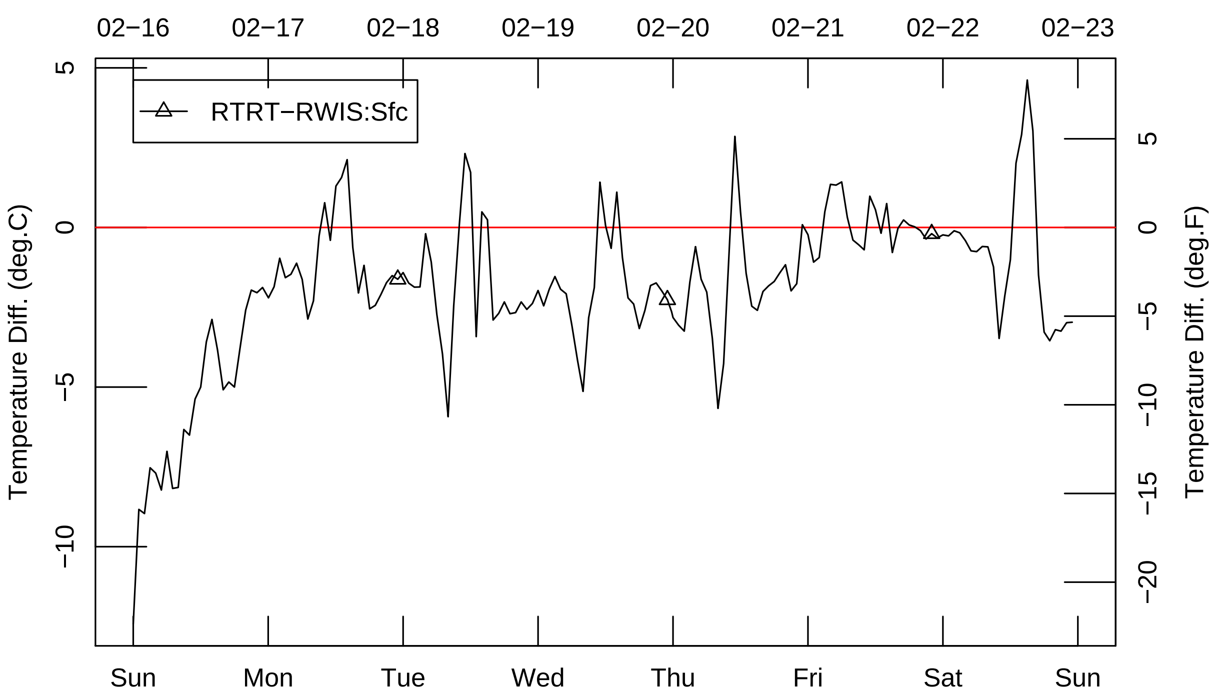

Figure 2: Temperature Difference

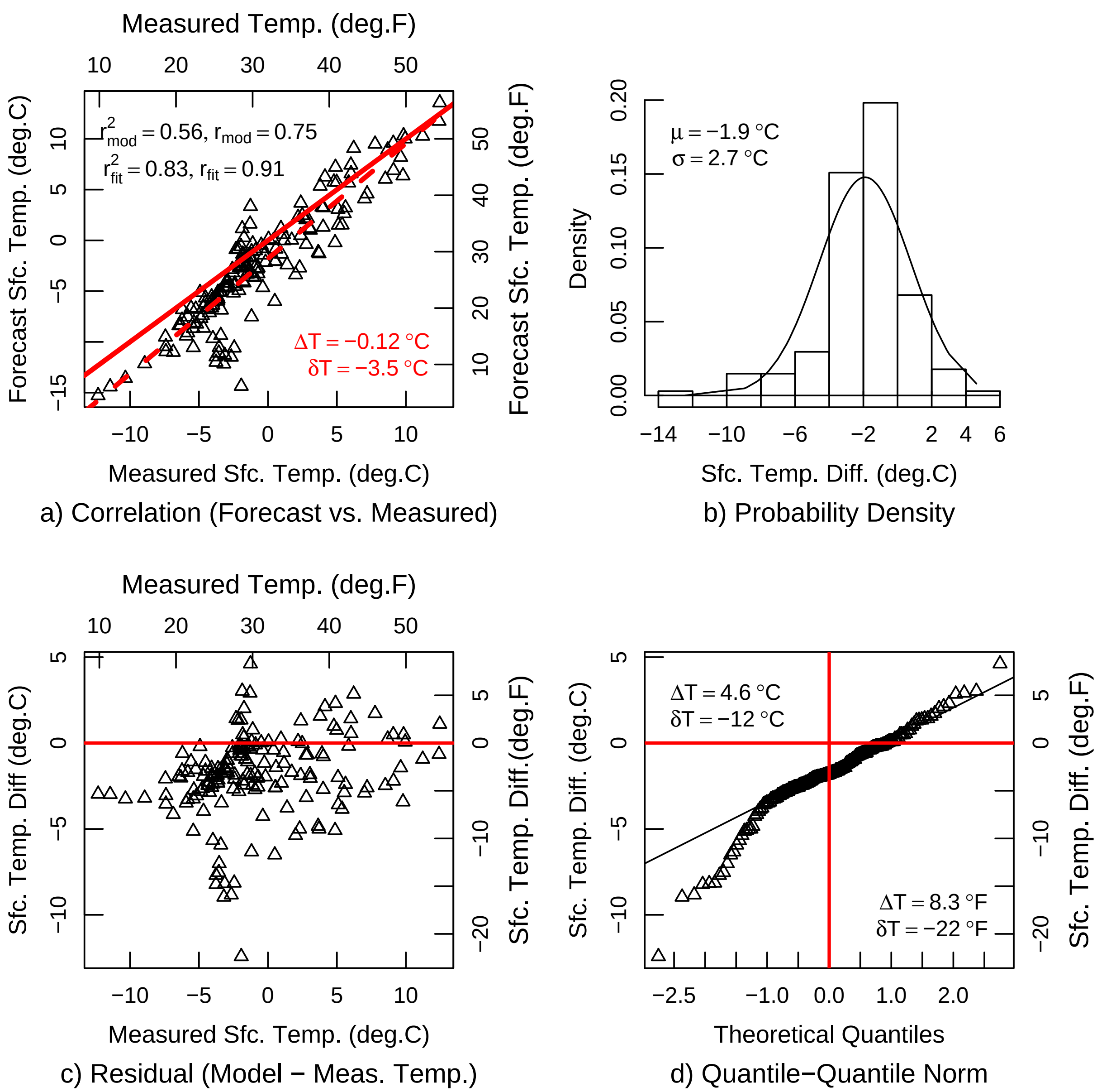

Figure 3: Model Statistics

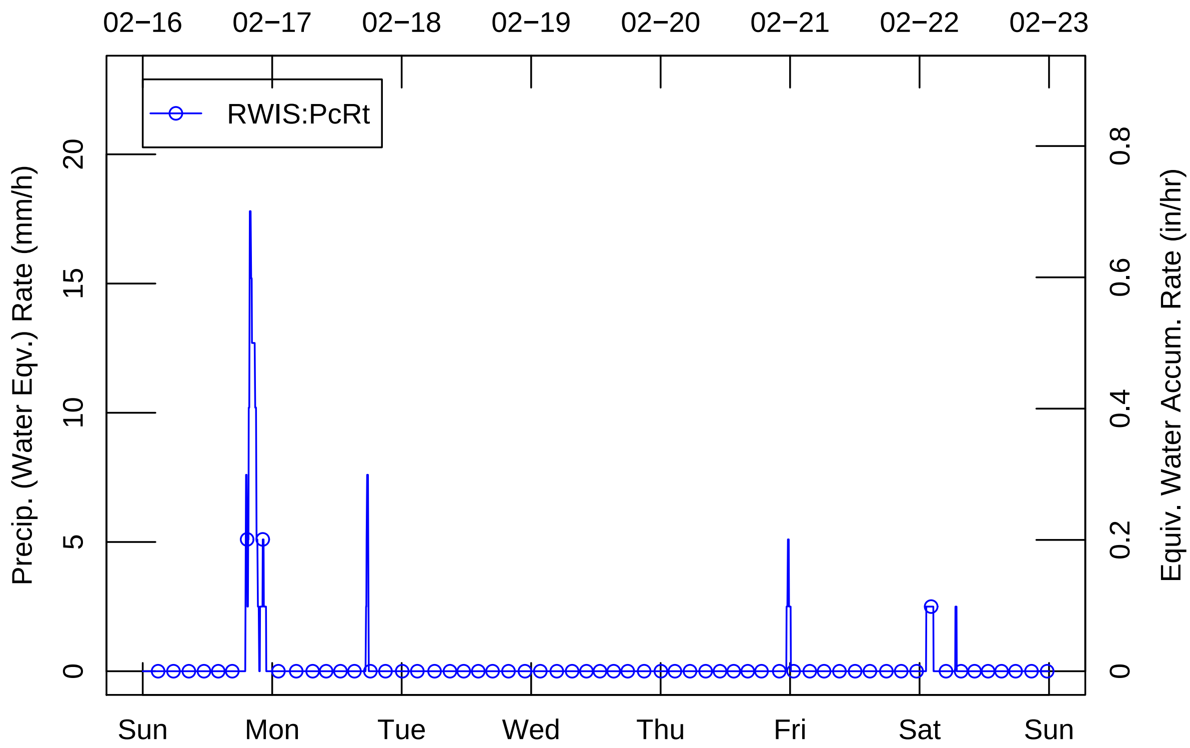

Figure 4: Temperature Difference

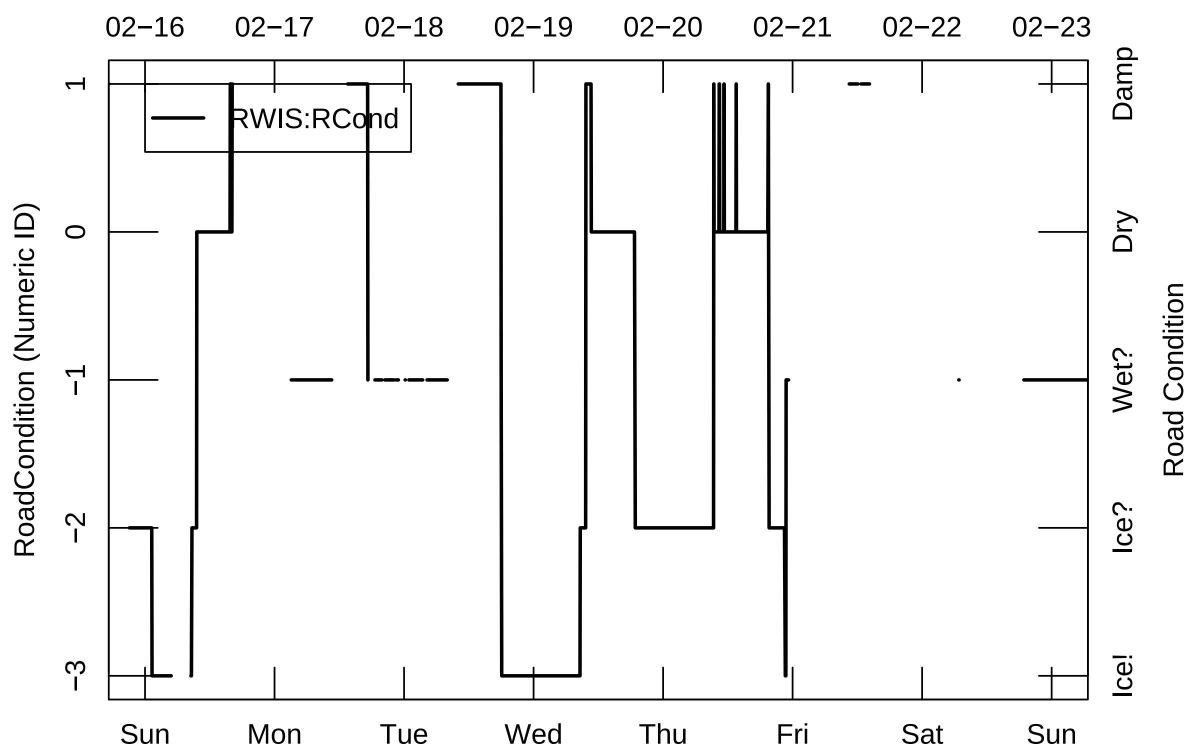

Figure 5: Model Statistics

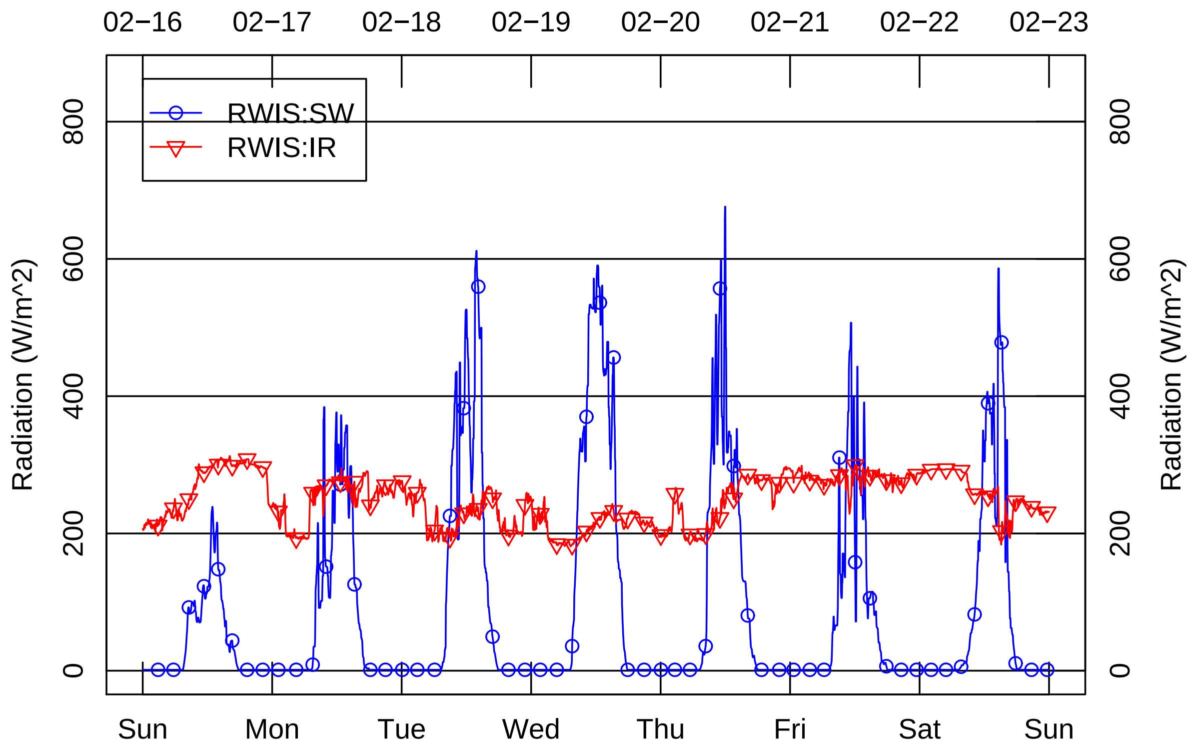

Figure 6: Radiation

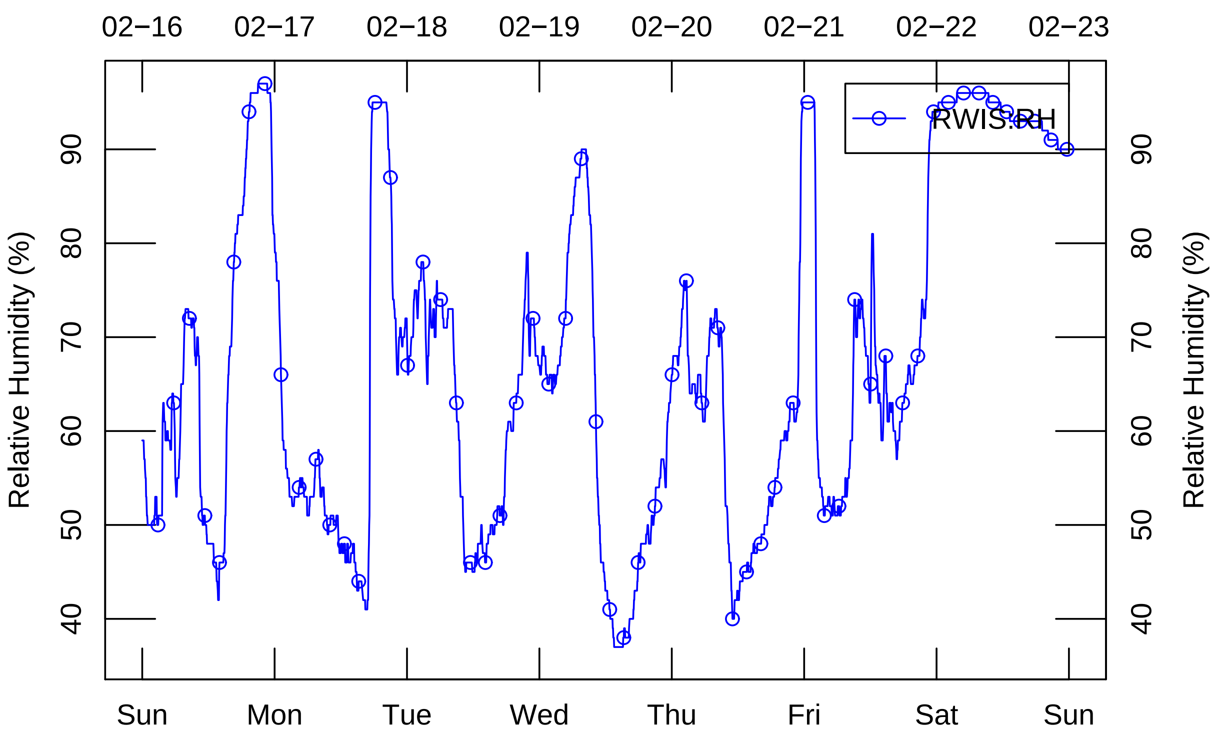

Figure 7: Relative Humidity

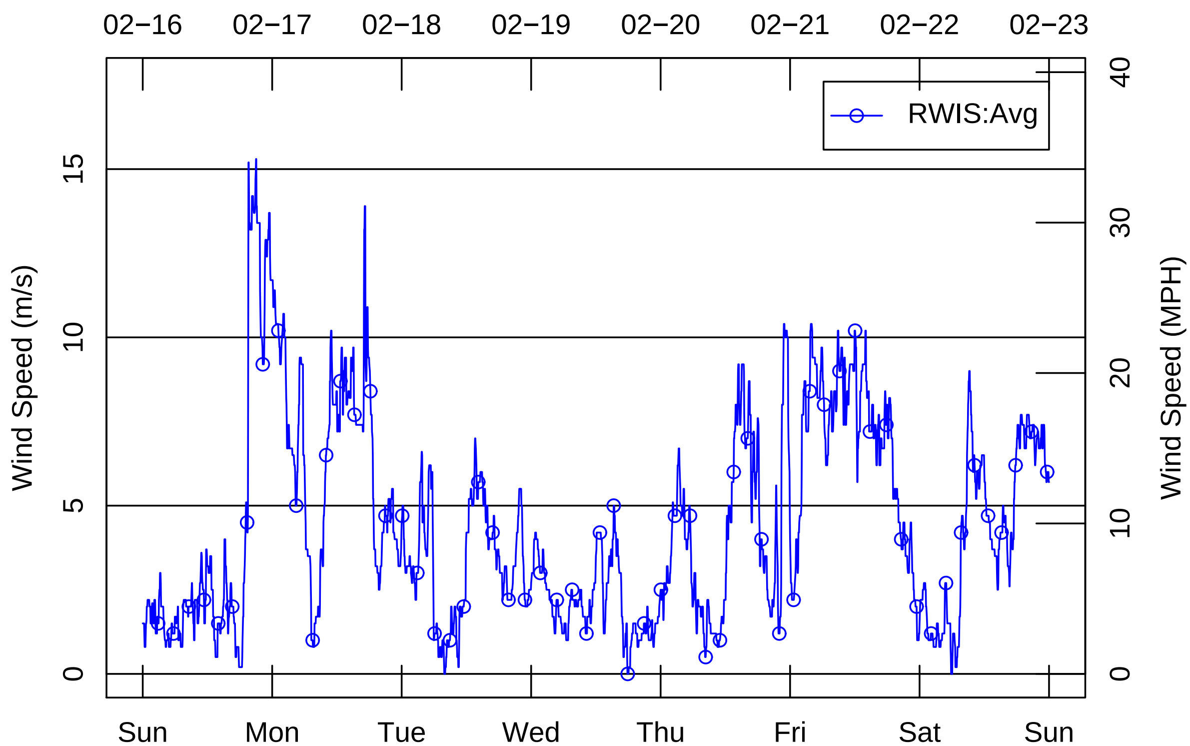

Figure 8: Wind Speed

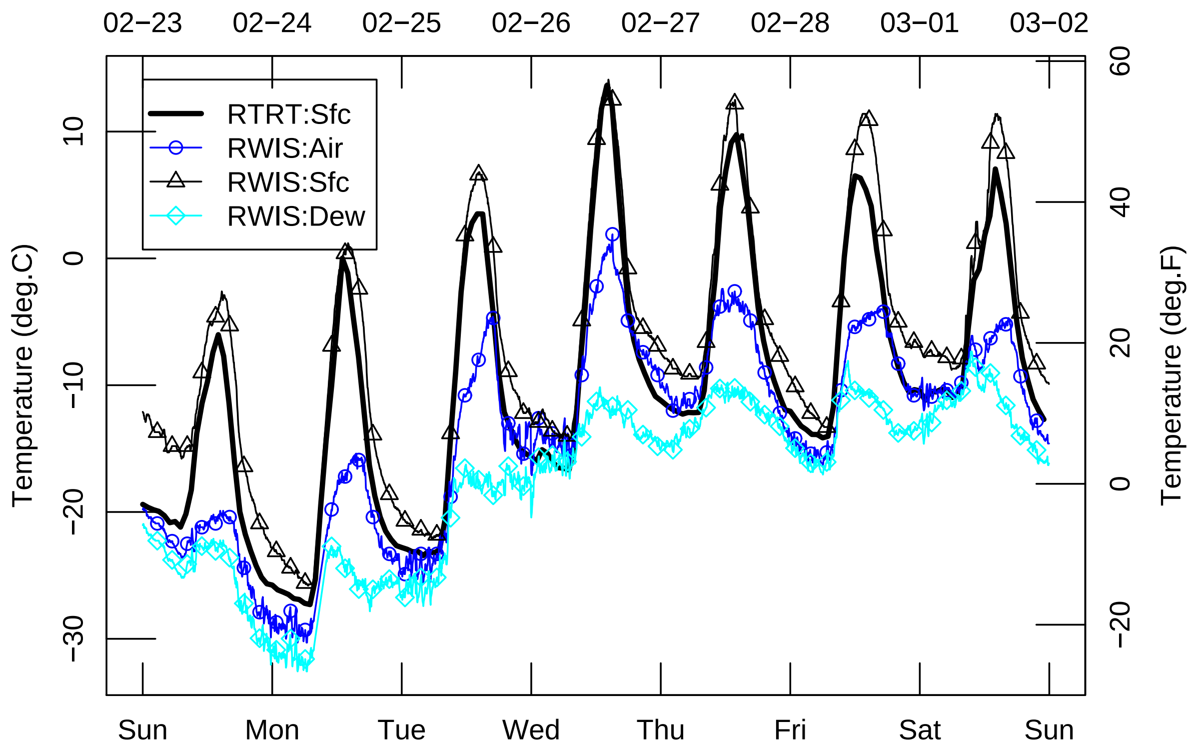

Figure 9: Temperature

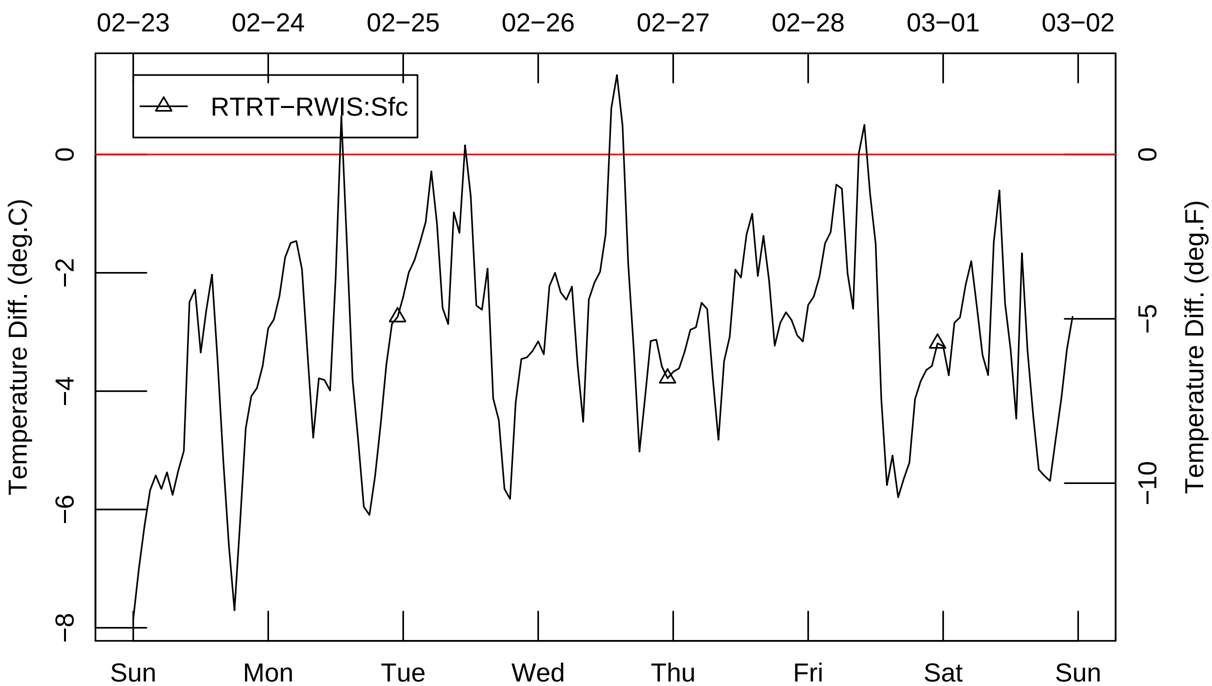

Figure 10: Temperature Difference

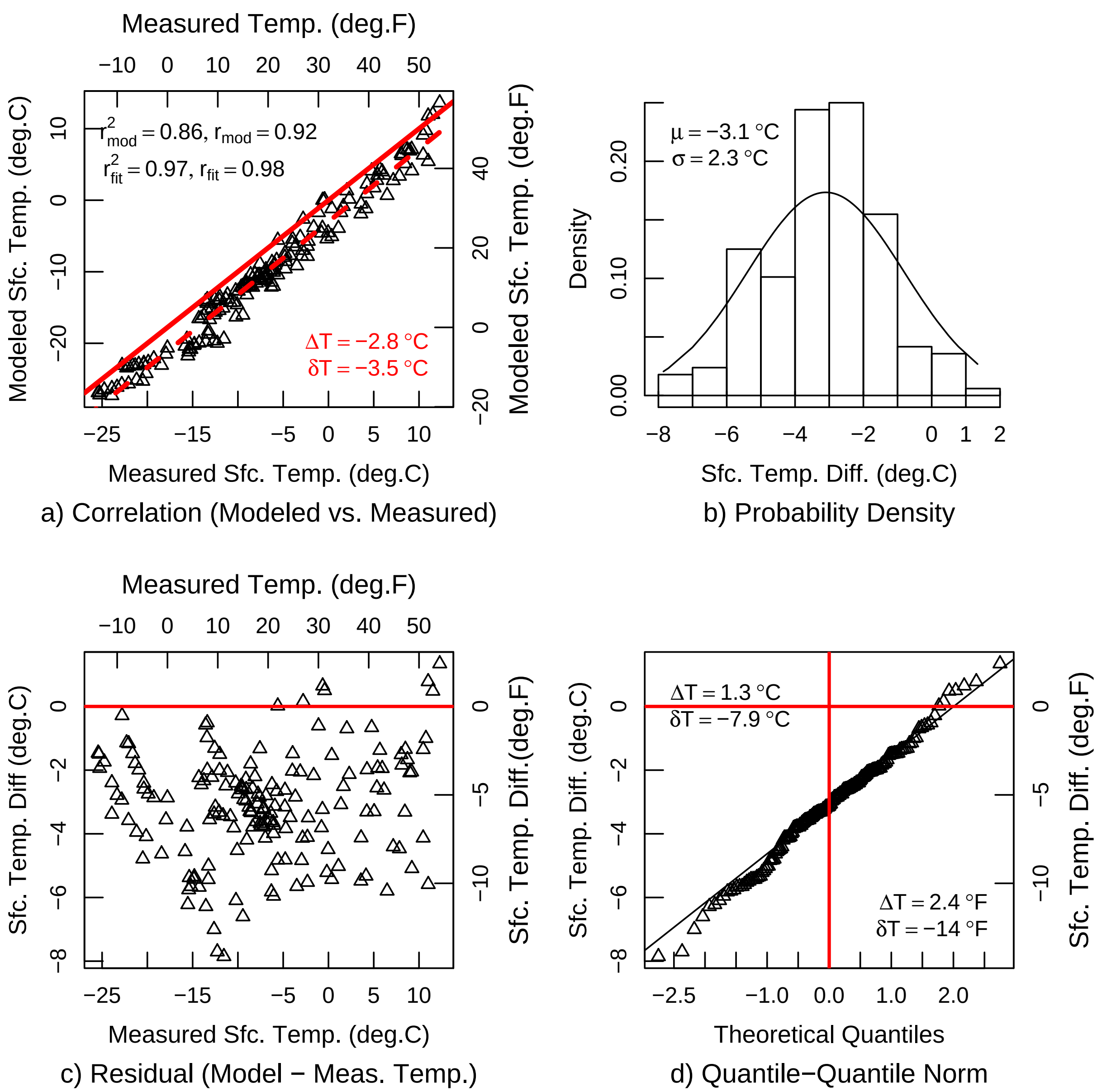

Figure 11: Model Statistics

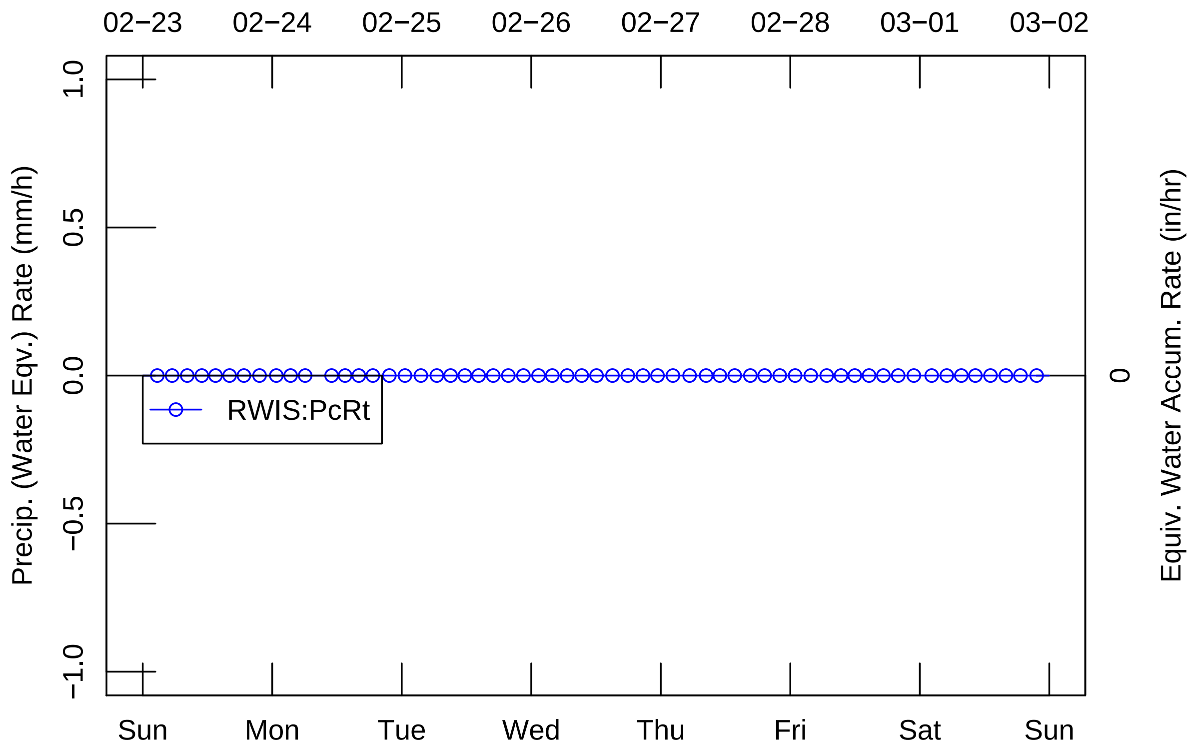

Figure 12: Temperature Difference

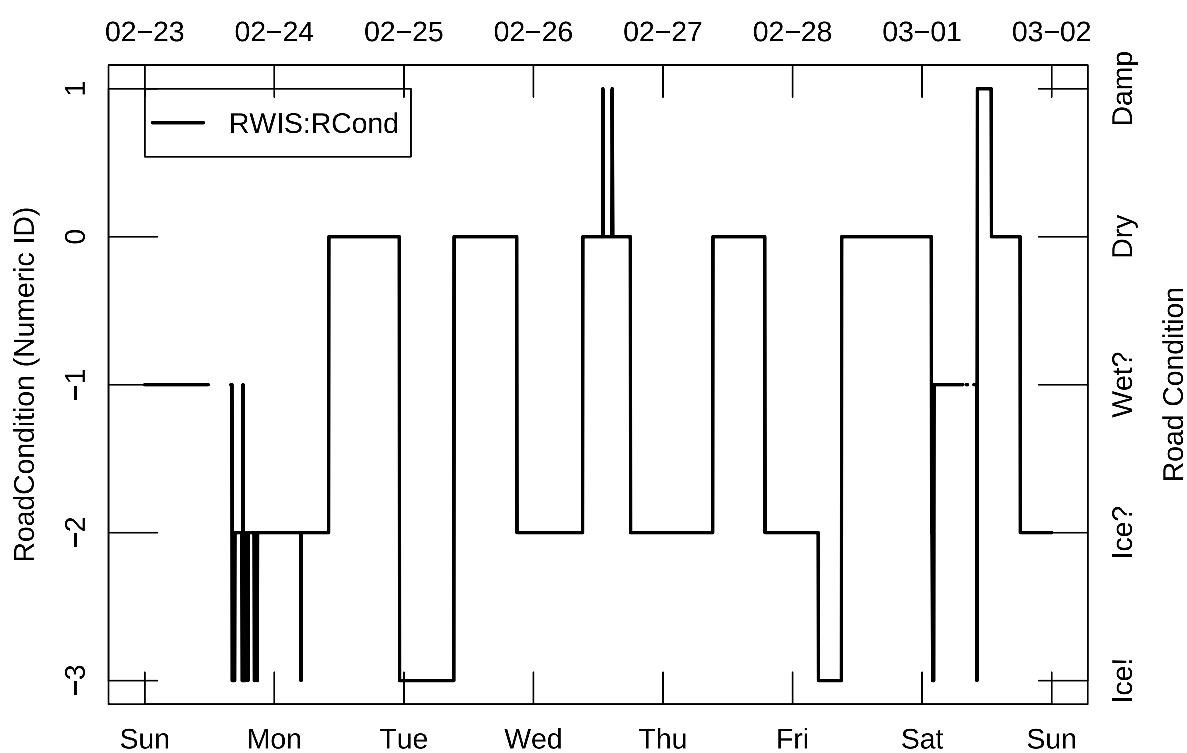

Figure 13: Model Statistics

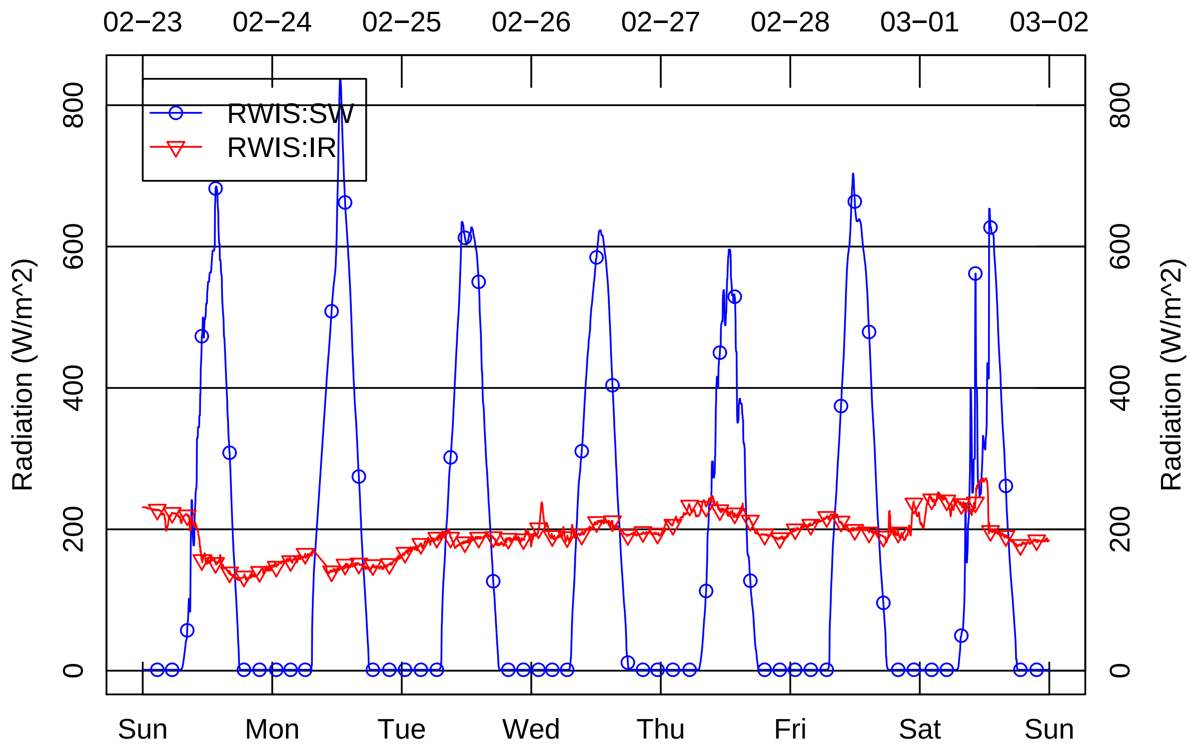

Figure 14: Radiation

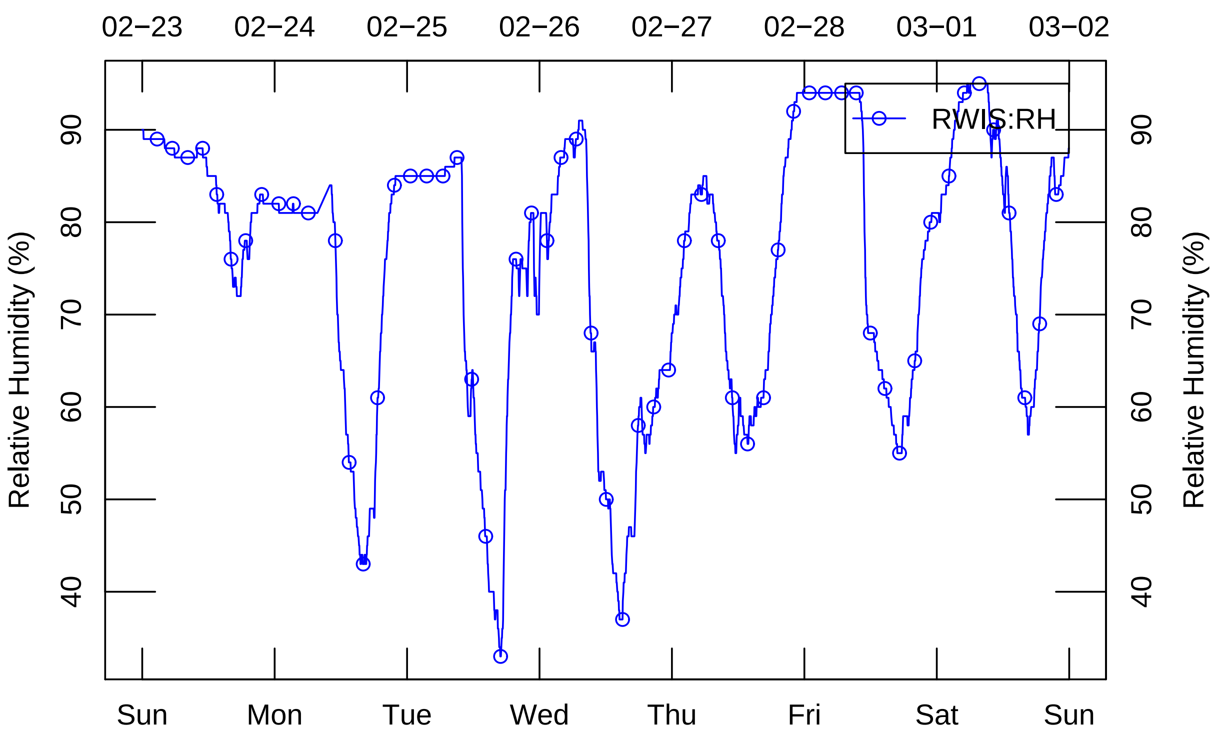

Figure 15: Relative Humidity

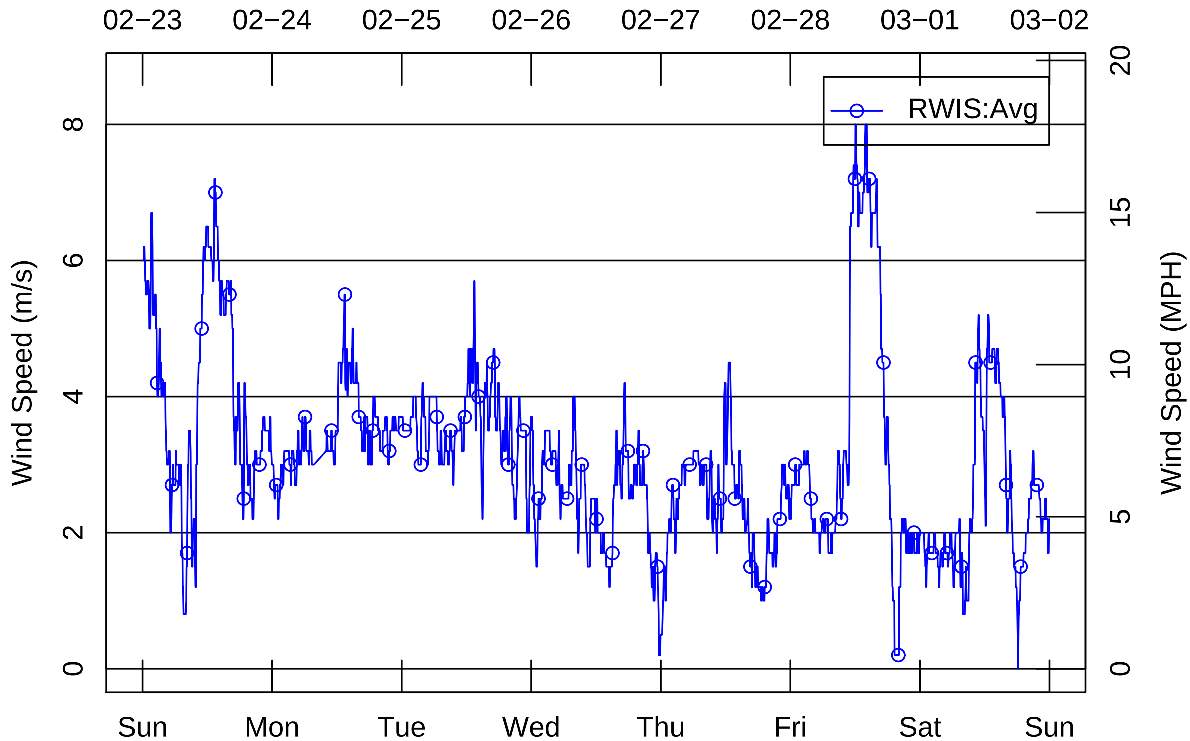

Figure 16: Wind Speed

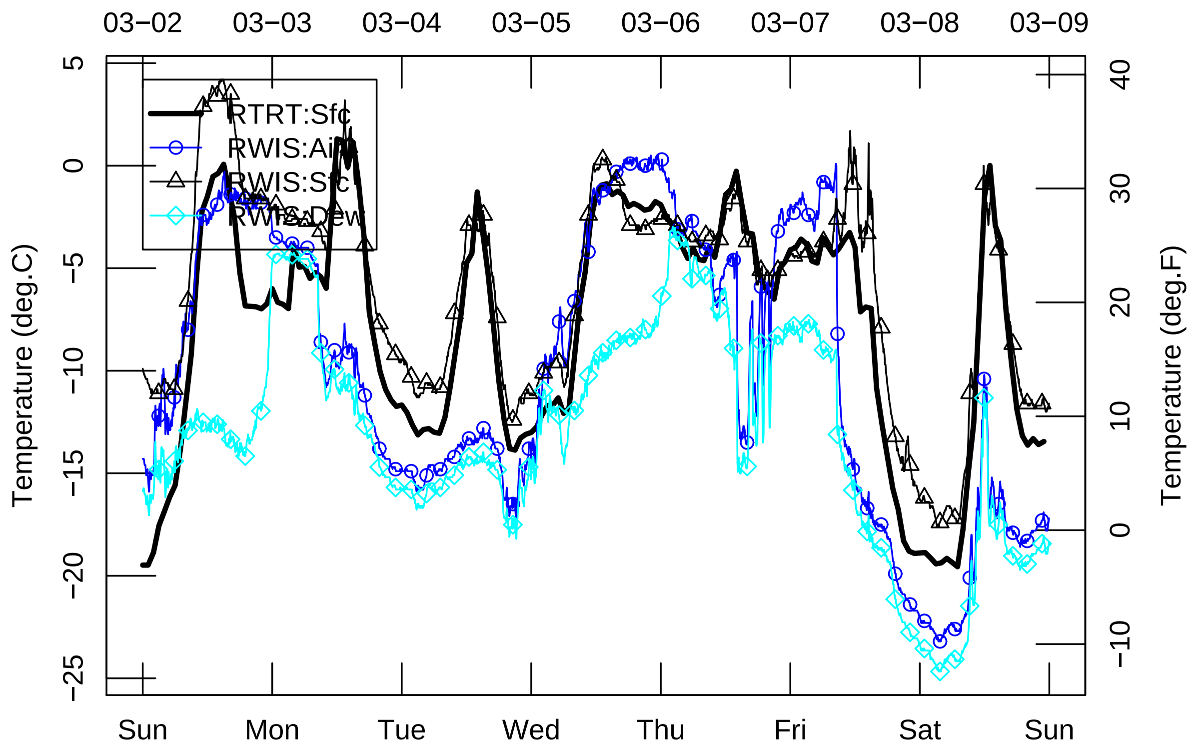

Figure 17: Temperature

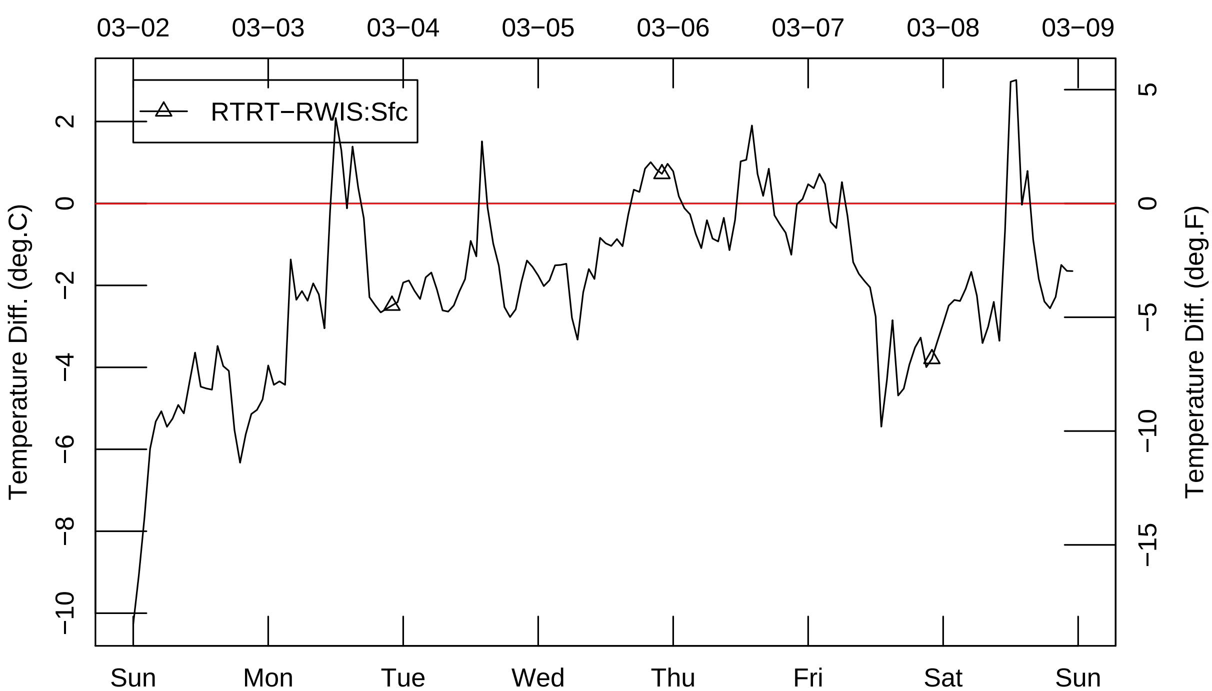

Figure 18: Temperature Difference

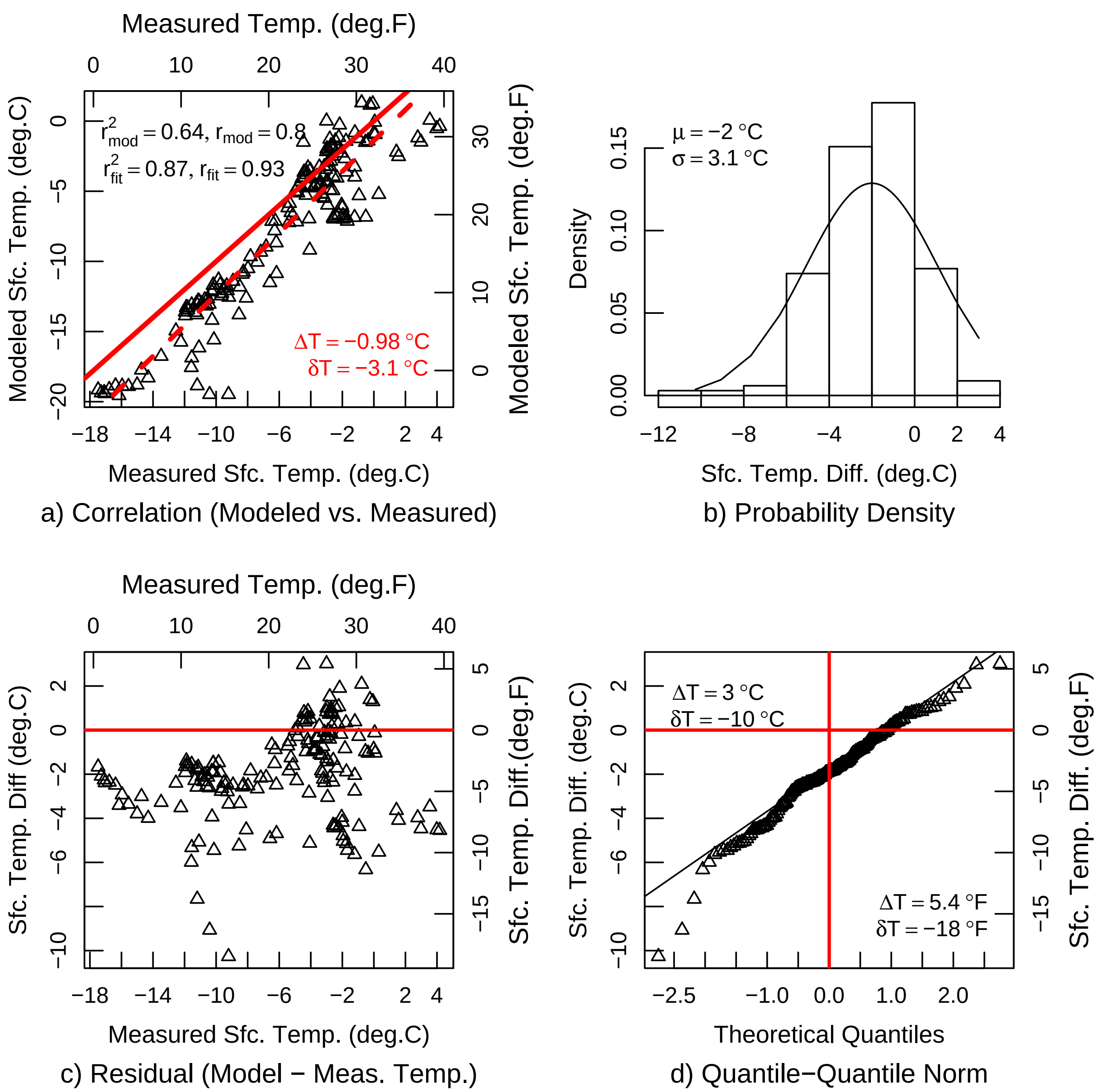

Figure 19: Model Statistics

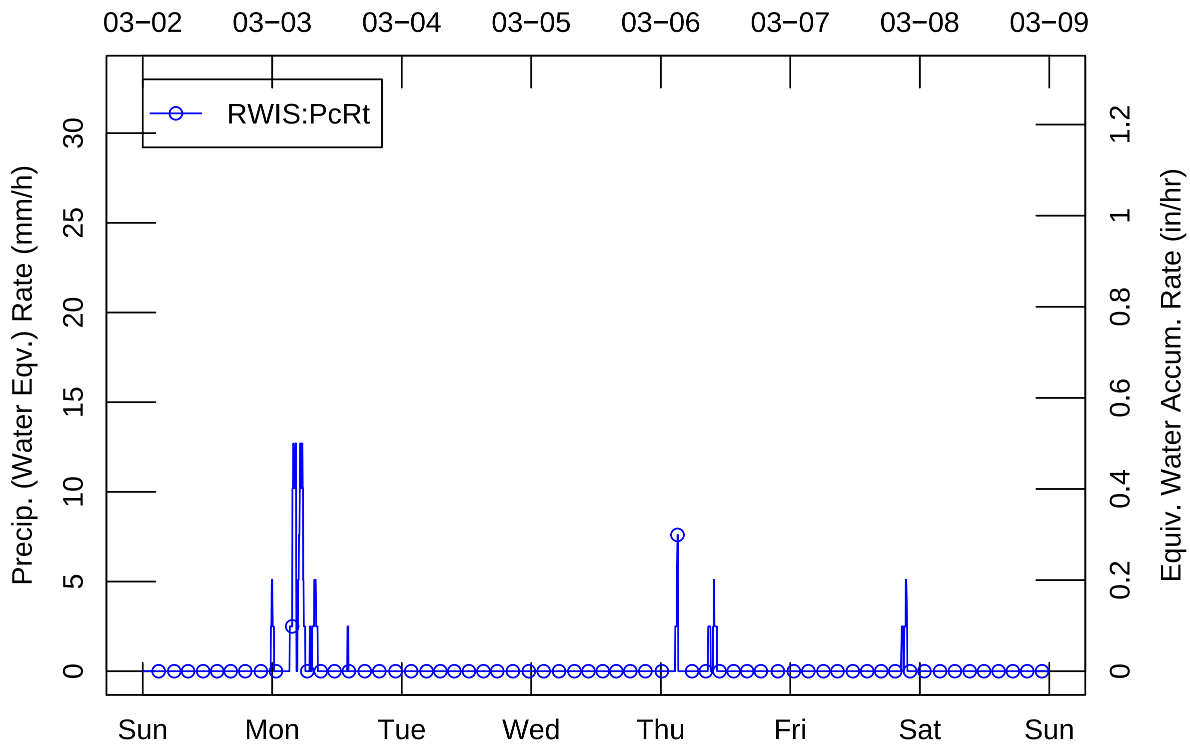

Figure 20: Temperature Difference

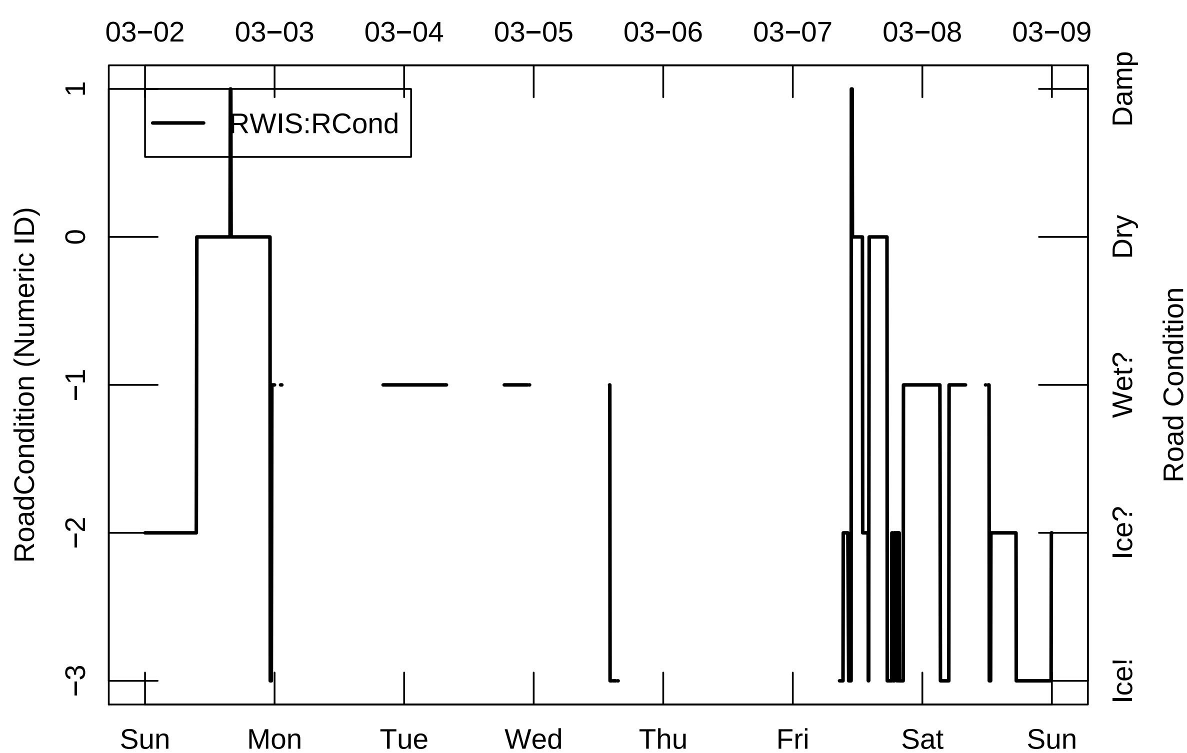

Figure 21: Model Statistics

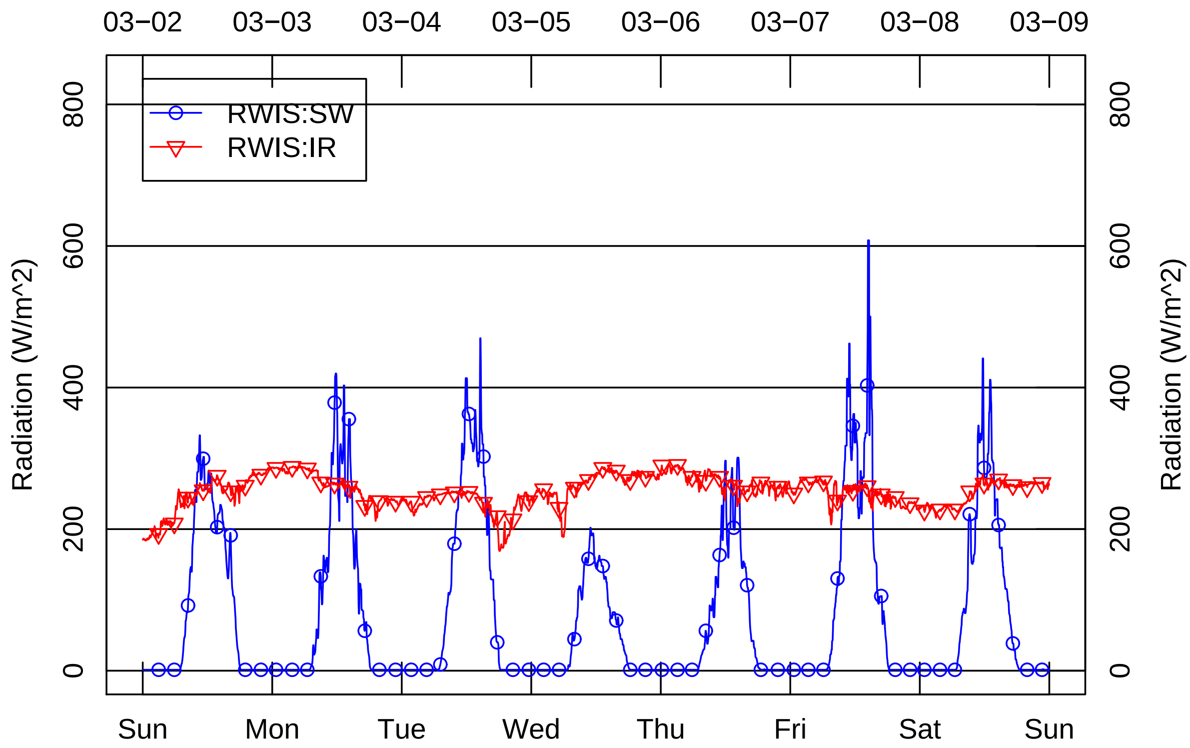

Figure 22: Radiation

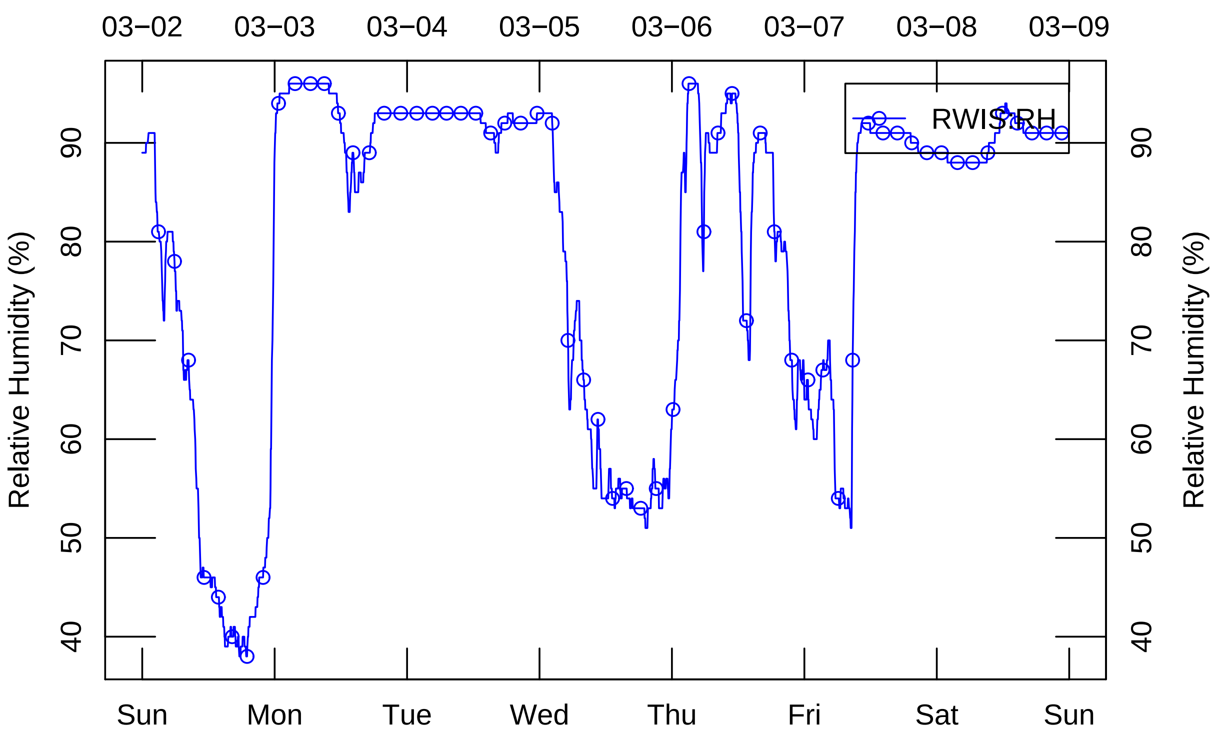

Figure 23: Relative Humidity

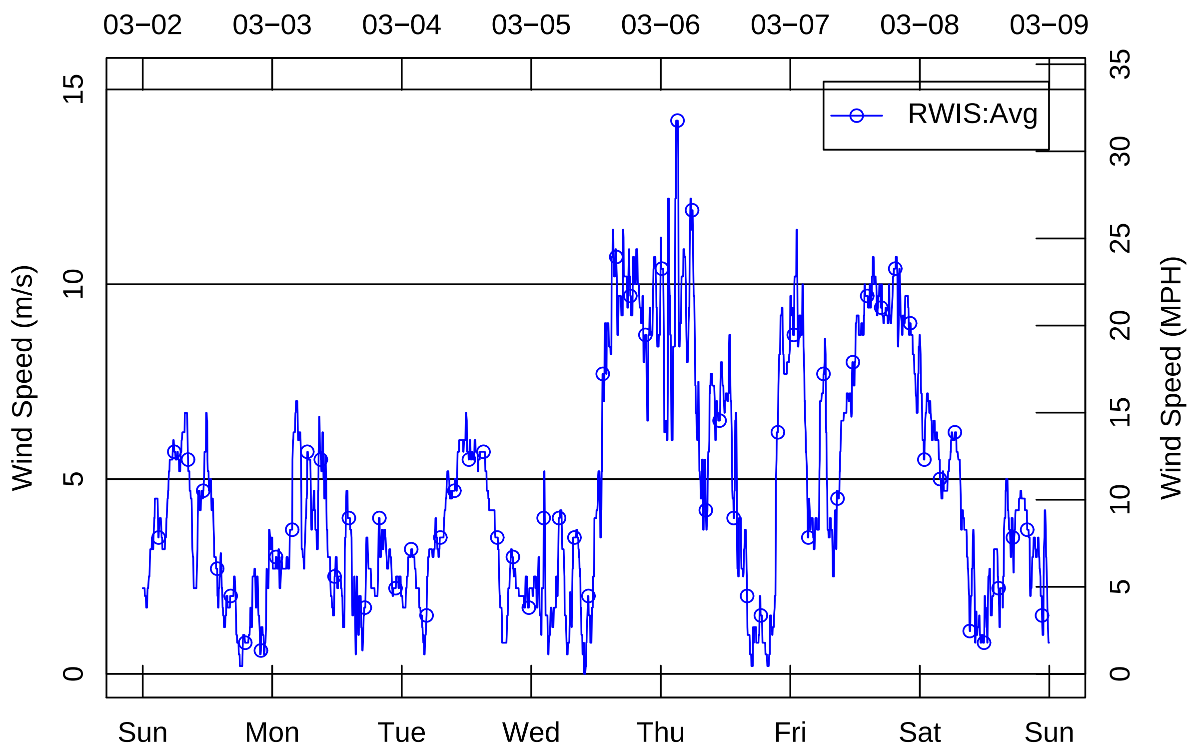

Figure 24: Wind Speed

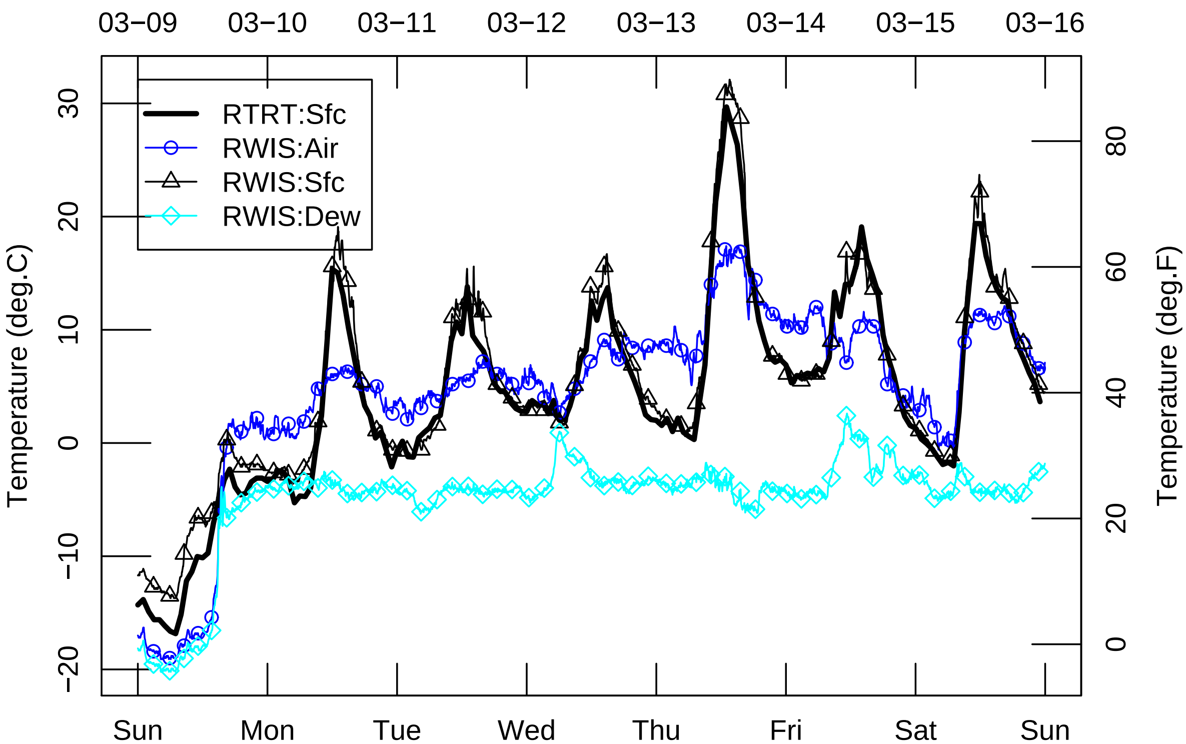

Figure 25: Temperature

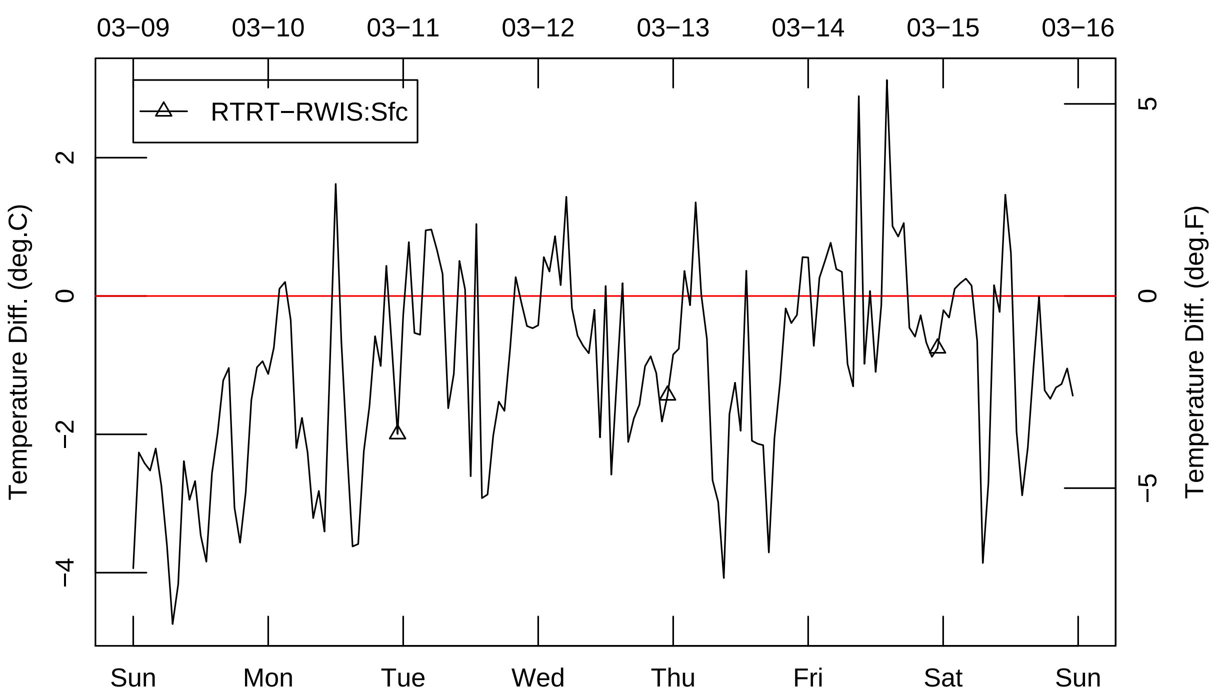

Figure 26: Temperature Difference

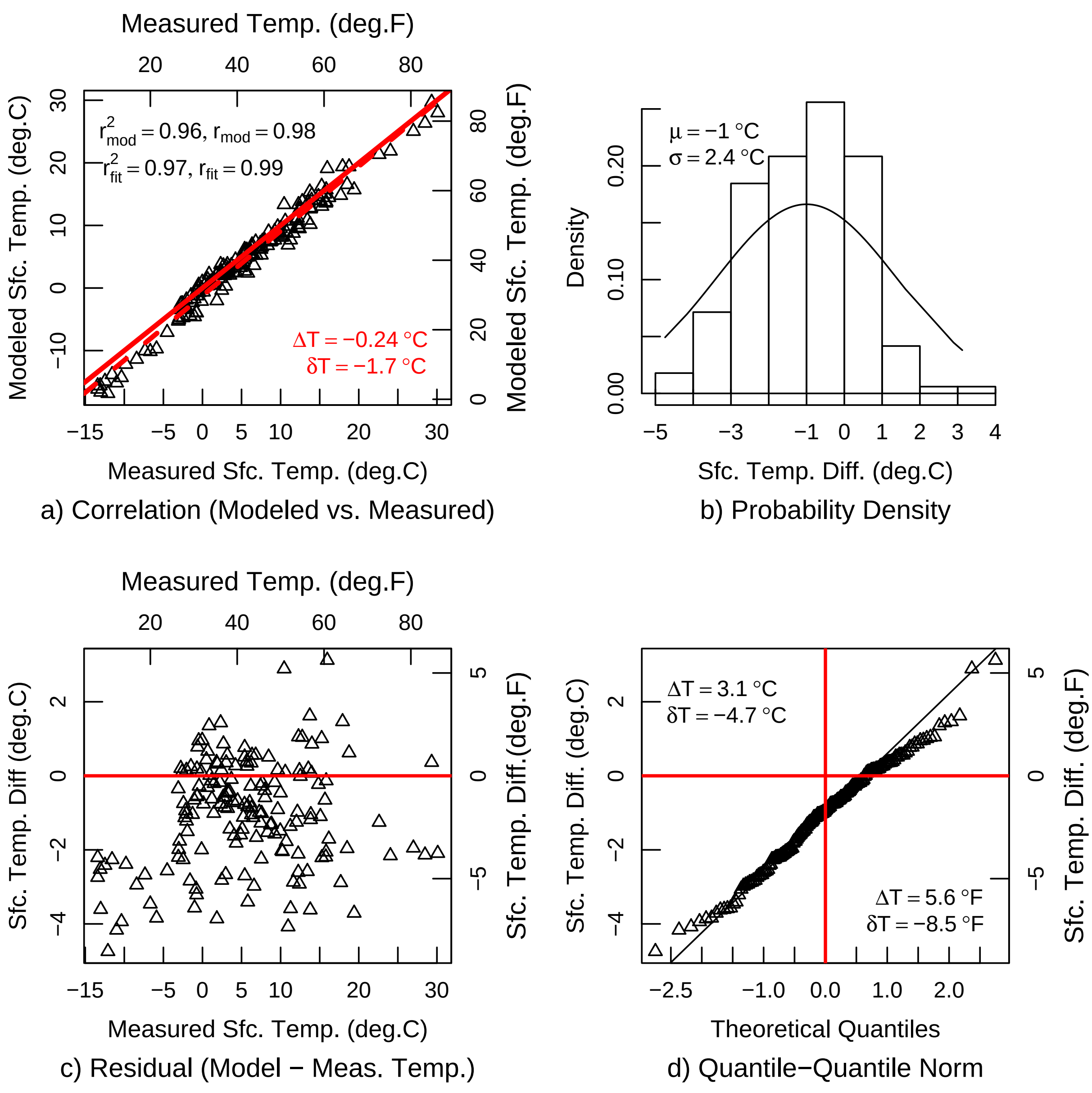

Figure 27: Model Statistics

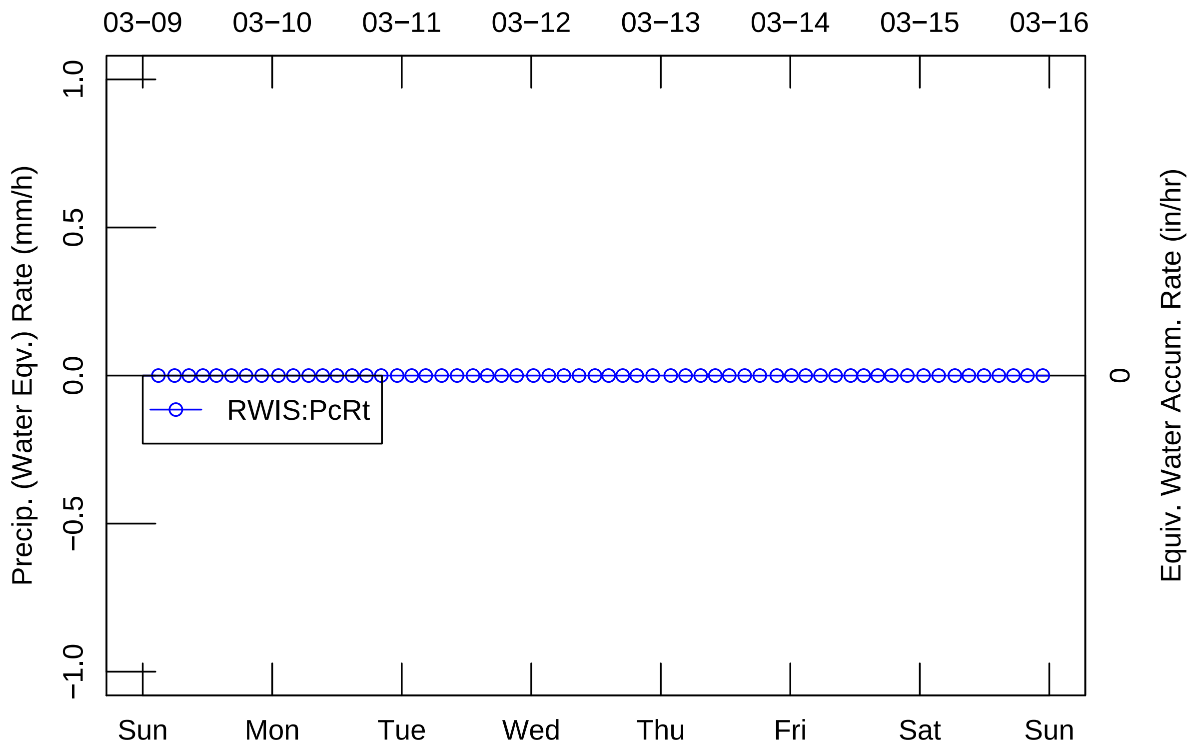

Figure 28: Temperature Difference

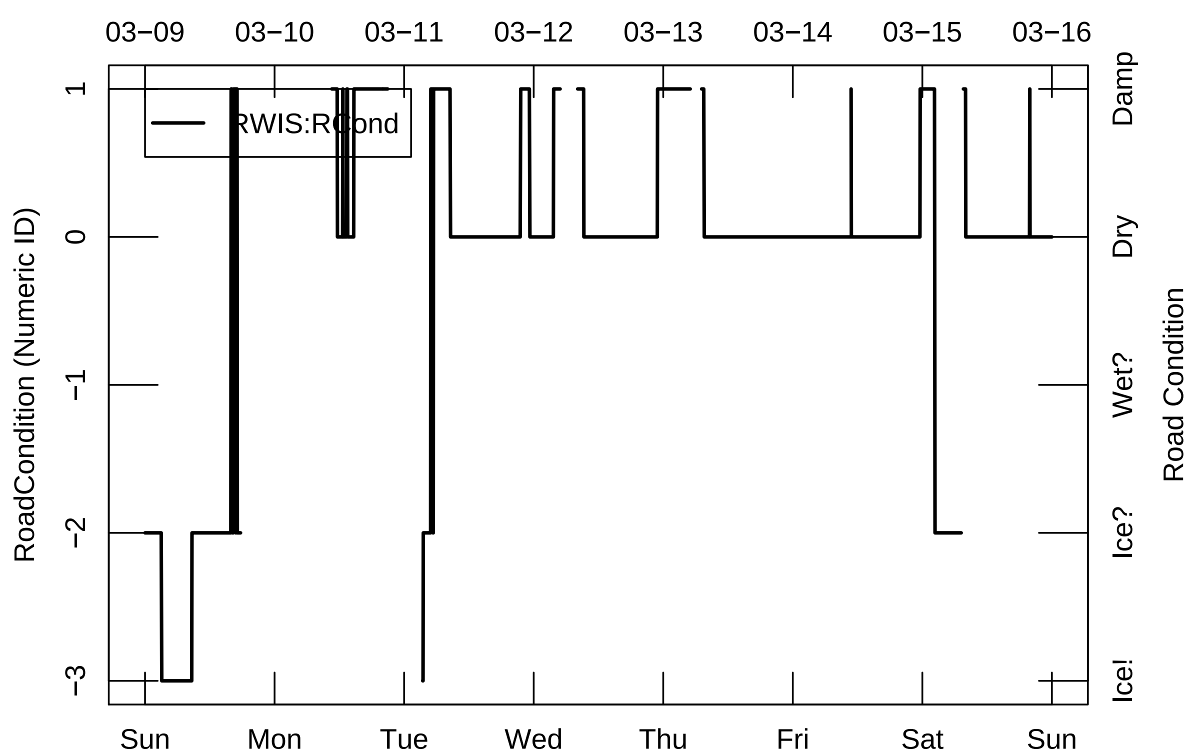

Figure 29: Model Statistics

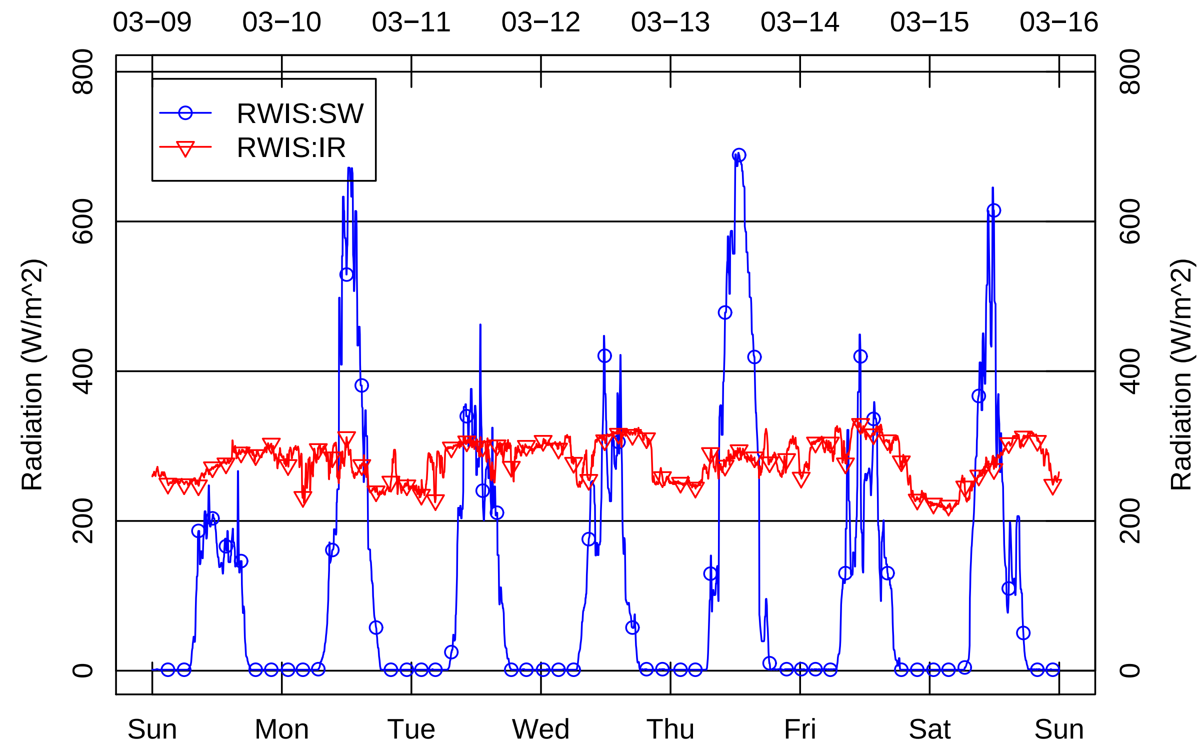

Figure 30: Radiation

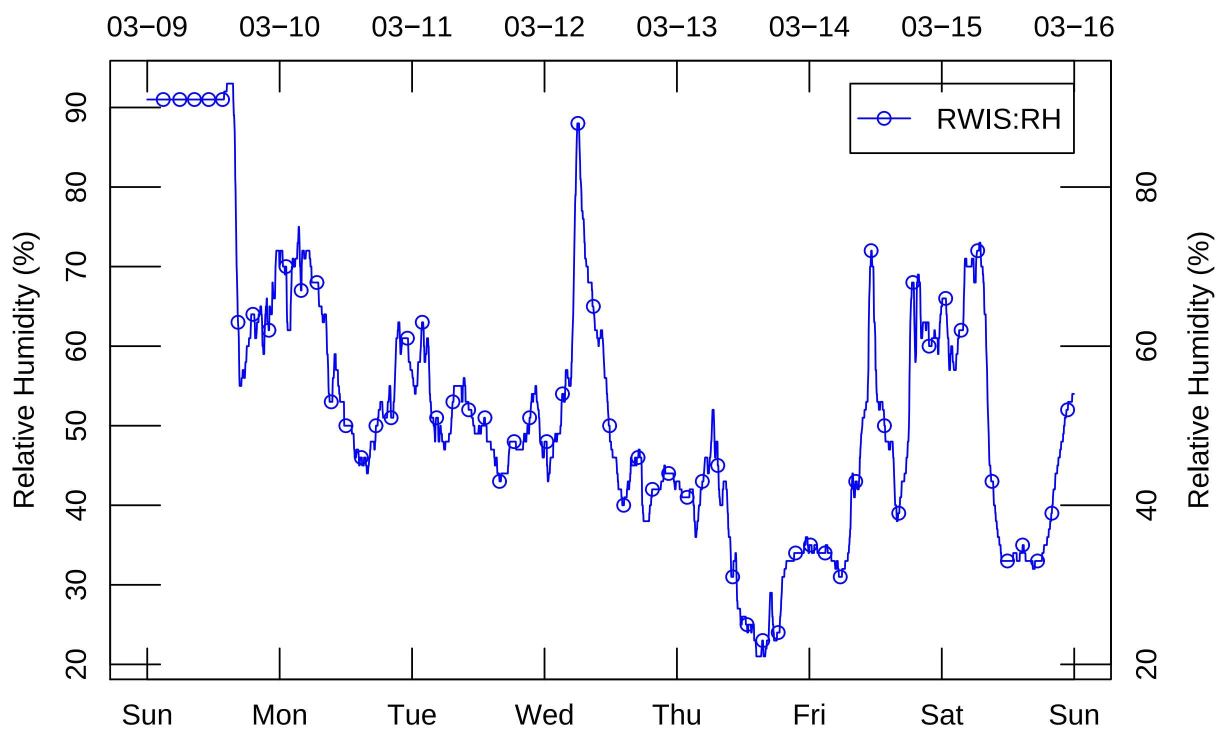

Figure 31: Relative Humidity

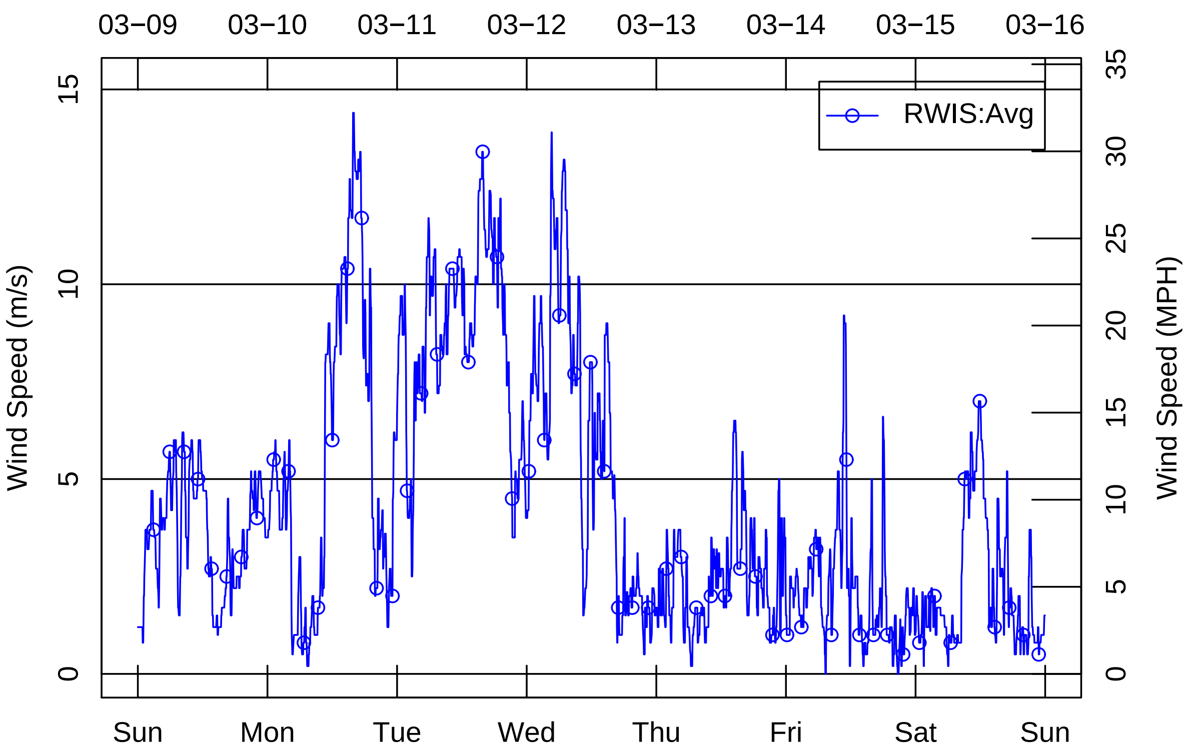

Figure 32: Wind Speed

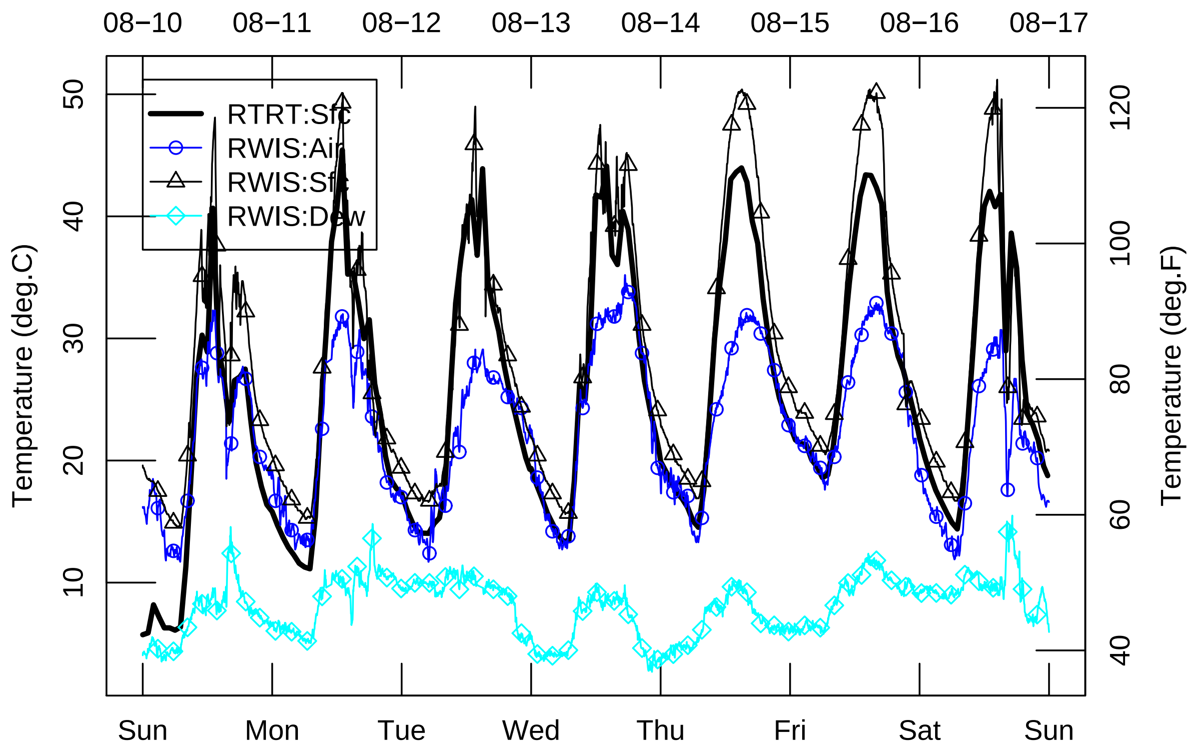

Figure 33: Temperature

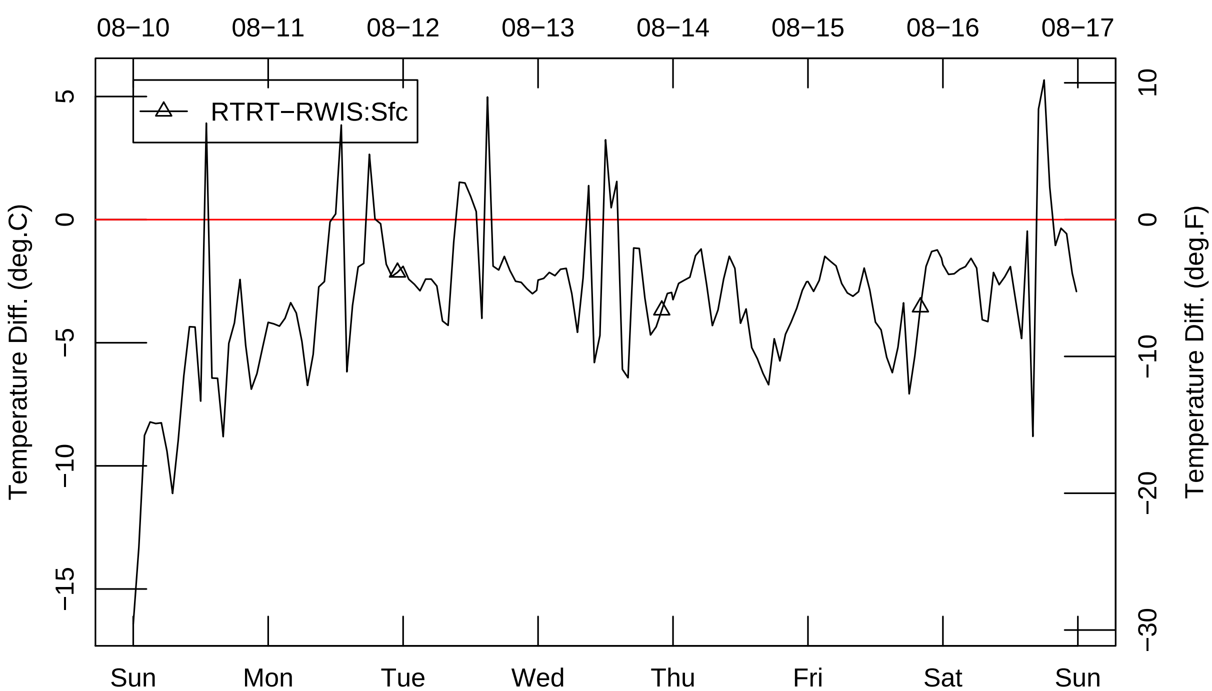

Figure 34: Temperature Difference

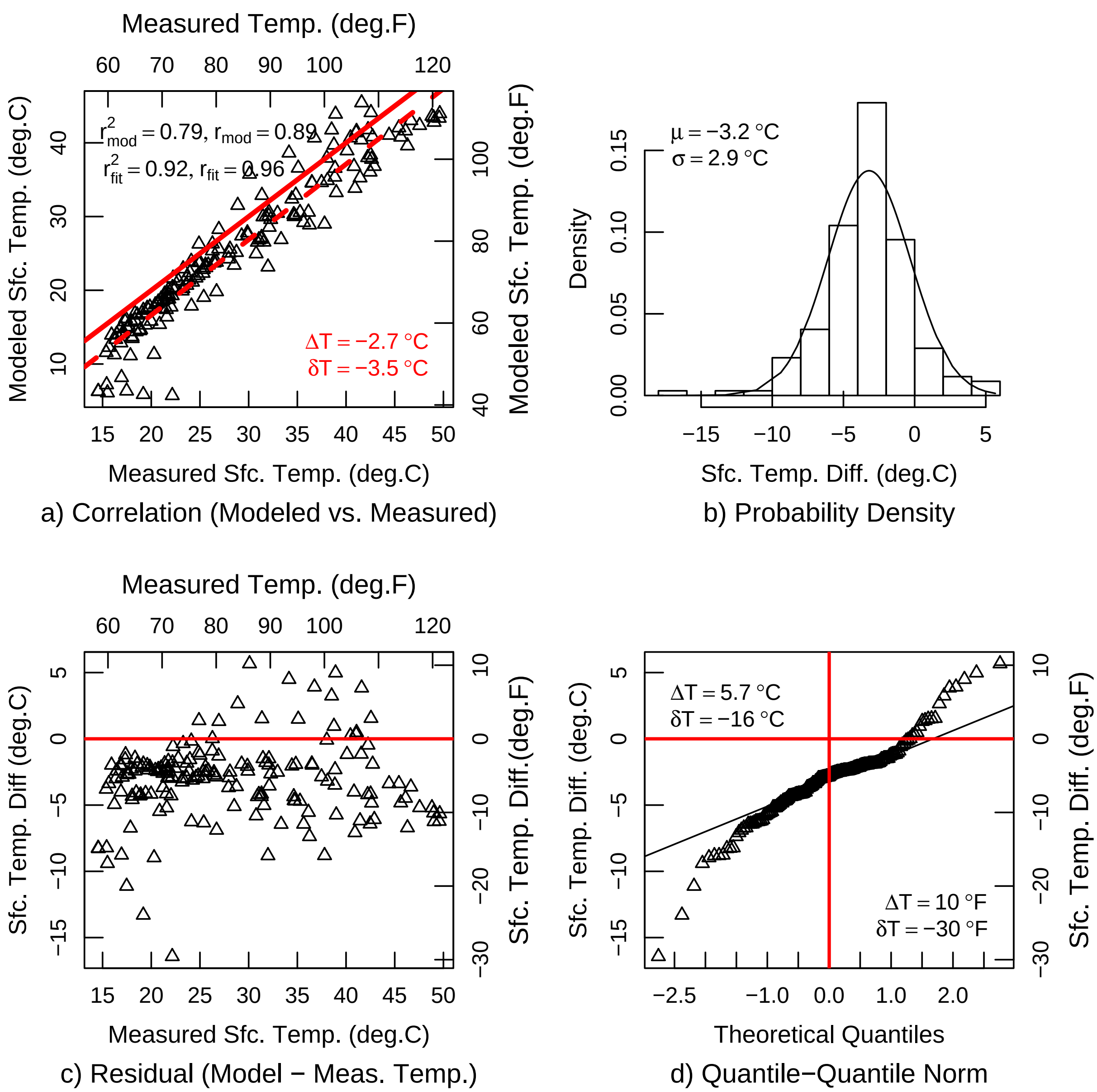

Figure 35: Model Statistics

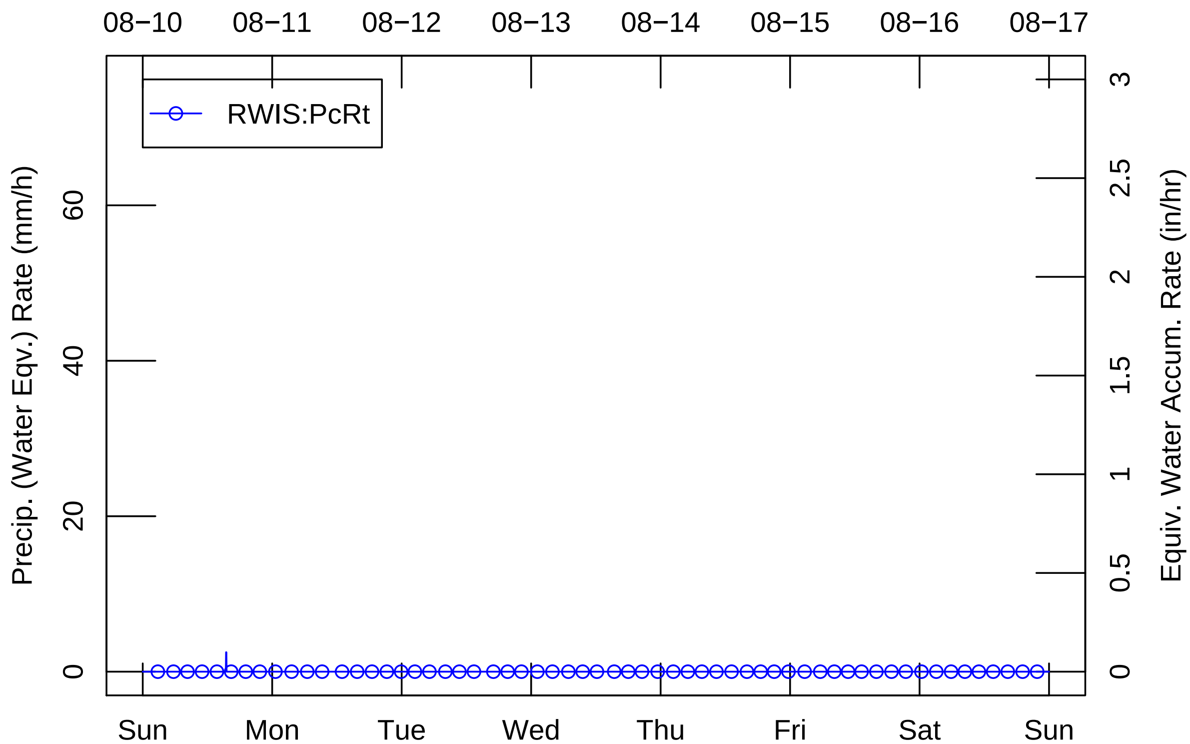

Figure 36: Temperature Difference

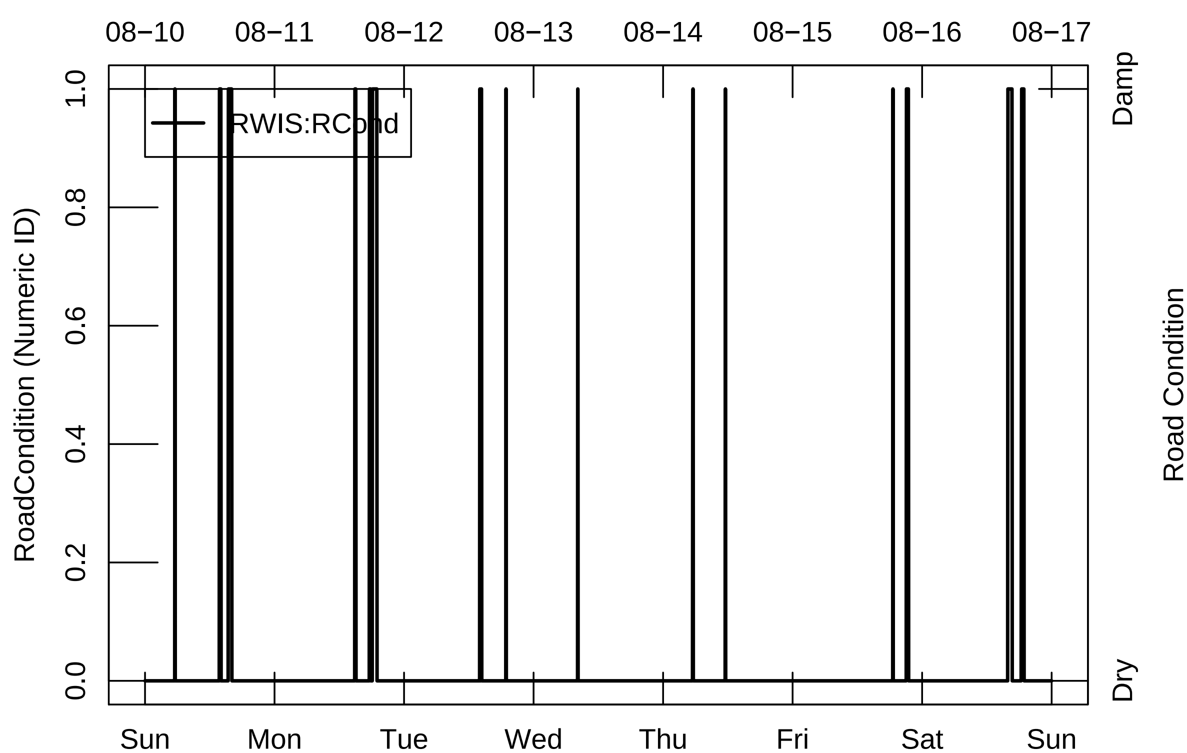

Figure 37: Model Statistics

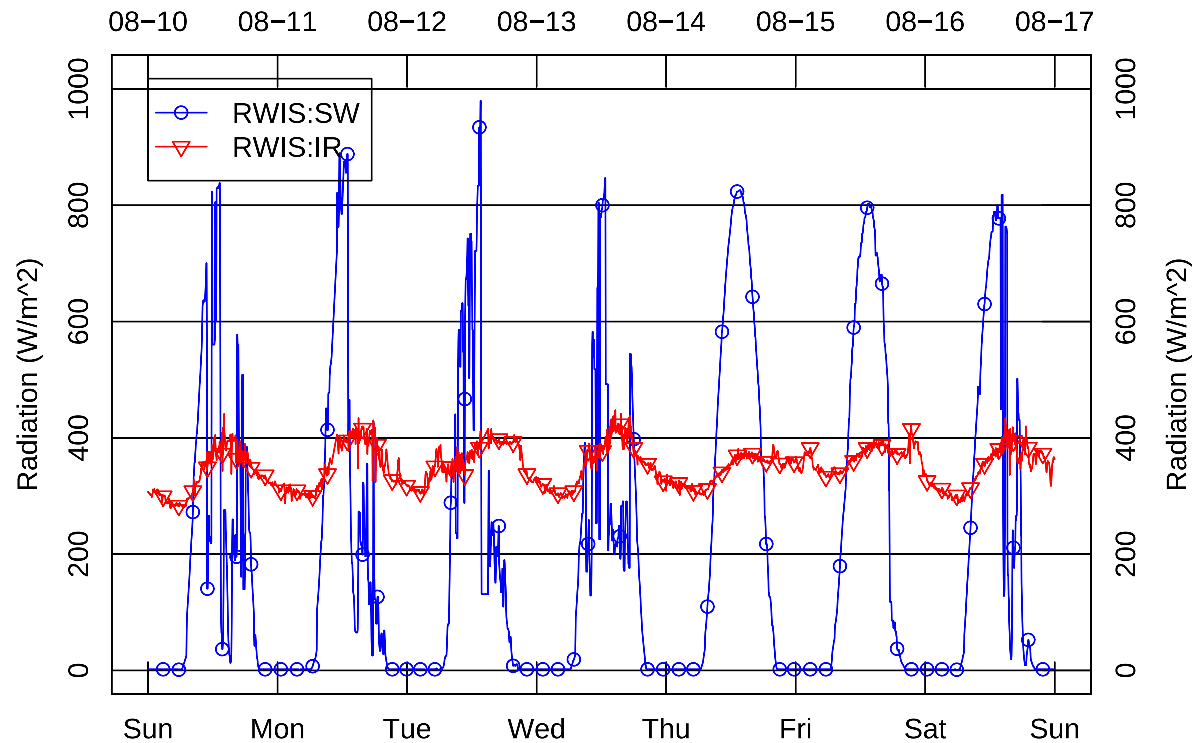

Figure 38: Radiation

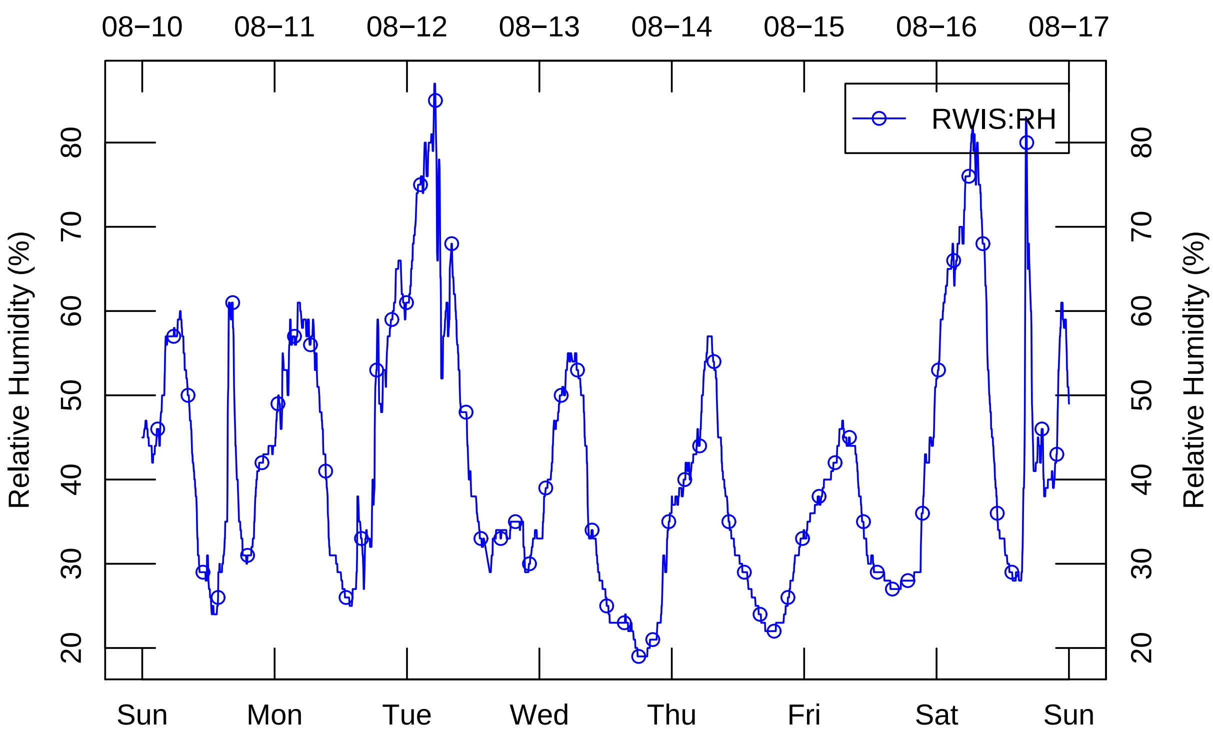

Figure 39: Relative Humidity

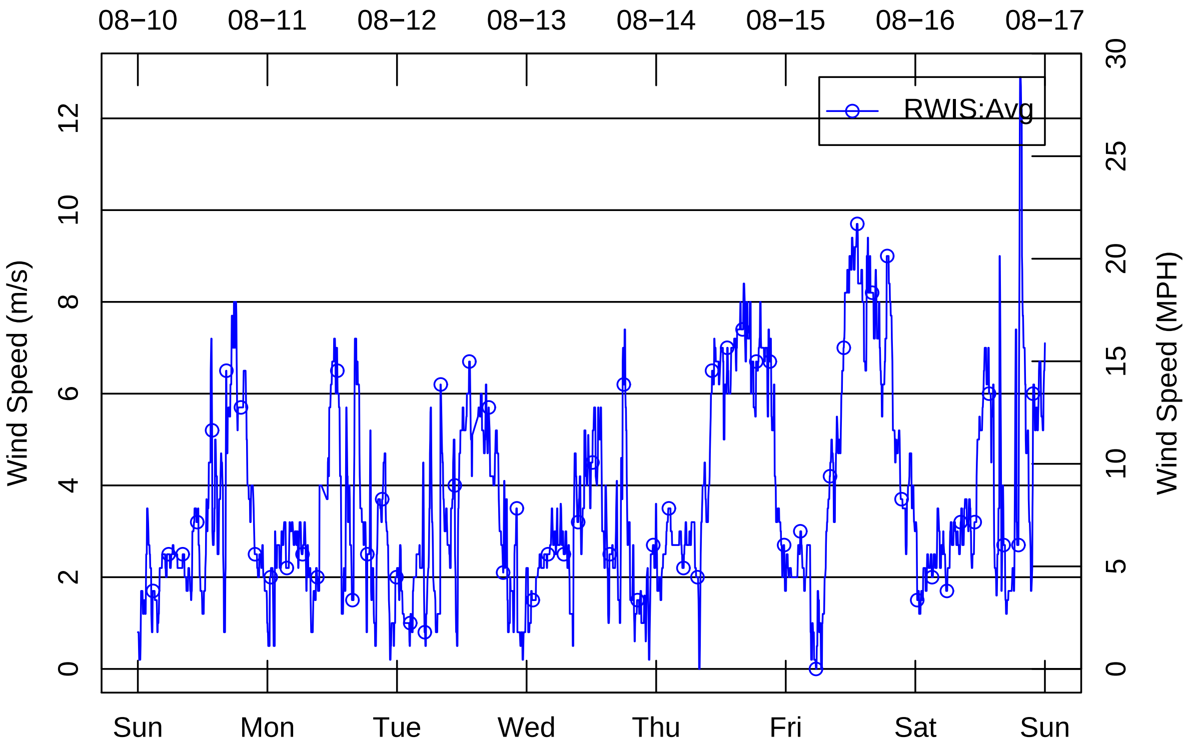

Figure 40: Wind Speed

10.REFERENCES

1 Highway Design and Operational Practices Related to Highway Safety, American Association of Highway and Transportation Officials, 1967.

2 The Forgiving Highway Concept, Federal Highway Administration, 1964.

3 Fighting Fog in Tennessee, Roads and Bridges, 1991.

4 Changeable Message Signs, NCHRP Synthesis of Highway Practice No. 61, 1979.

5 Human Factors Requirements for Real-Time Motorist Information Displays, Report No: FHWA-RD-78, 1978

6 Adams, E.E., Jodi Carson, and John Mounce, SAFE-PASSAGE: Development and Demonstration of a Rural Weather Prediction Model and Motorist Communications System for Safe and Efficient Traffic Management/Infrastructure Maintenance-First Year Report. September 1999.

7 Adams, E.E., Jodi Carson, and John Mounce. SAFE-PASSAGE: Development and Demonstration of a Rural Weather Prediction Model and Motorist Communication System for Safe and Efficient Traffic Management/Infrastructure Maintenance-Second Year Report. September 2000.

8 Bylsma, Ryan, E.E. Adams, Jodi Carson, and John Mounce. SAFE-PASSAGE: Development and Demonstration of a Rural Weather Prediction Model and Motorist Communication System for Safe and Efficient Traffic Management/Infrastructure Maintenance-Third Year Report. September 2001.

9 Bylsma, Ryan, E.E. Adams, and J.M. Mounce. SAFE-PASSAGE: Development and Demonstration of a Rural Weather Prediction Model and Motorist Communication System for Safe and Efficient Traffic Management/Infrastructure Maintenance – Fourth Year Report, September 2002.

10 Montana Department of Transportation, Planning Section, 2000.

11 Montana Department of Transportation, Safety Management Section, 2000.

12 A Study of Large Trucks, Montana Department of Transportation, 1995.

13 Adams, E. E., Proof of Concept for Prediction of Pavement Temperature: A Tactical Decision Aid for Highway Safety: Final Report prepared for the State of Montana Department of Transportation. FHWA/MT-99-003/8117, 1999.

14 Johnson, K.R., Technical Reference Guide for TCM2, Interim Report to Wright Laboratory Avionics Directorate, Wright-Patterson AFB, OH, May 1991.

15 Johnson, K.R., et.al., Phase 2 Development Tasks: Research to Enhance the Phillips Laboratory SIMLAB Capability for Simulating the IR Scene, Final Report to Phillips Laboratory, Hanscom AFB, MA, January 1996.

16 Prism 3.0 User's Manual, Keweenaw Research Center, Michigan Technological University, Houghton, MI USA, 3.0 edition, 1991.

17 Adams, E.E. and S.A. McDowell, Thermal Model for Snow on Three Dimensional Terrain, Proceedings of Japan-U.S. Symposium on Snow Avalanche, Landslides,

Debris Flow Prediction and Control, Tsukuba, Tsukuba-shi, Ibaraki-ken, Japan. September 1991(a).

18 Adams, E.E and S.A. McDowell, Influence of Topography on Mass Exchange at a Snow Surface, American Geophysical Union fall Meeting, San Francisco, Ca, December 1991(b).

19 Adams, E.E, R.G. Alger and J.P. Beckwith, Influence of Wind, Temperature and Deicing Chemicals on Snow Accretion, Transportation Research Record Highway Maintenance Operations and Research 1991, Transportation Research Board, National Research Council, No. 1304, pg. 182-187, 1991.

20 Adams, E.E., R.G. Alger, J. Chekan, F.W. Williams and R. Valverde, Persistence of Reduced Snow to Pavement Shear Strength for Two Aggregate Materials Treated with CMA and CaCl, Chapter in Chemical Deicers and the Environment (F.M. D'Itri, ed.) Lewis Publishers, Inc., Ann Arbor, MI, 1992.

21 Alger, R.G., J.P. Beckwith and E.E. Adams, A Comparison of Liquid and Solid Chemicals for Anti-icing Application on Pavements, Transportation Research Record, Maintenance of the Highway Infrastructure, Transportation Research Board, National Research Council, No. 1442, pg. 162-169, 1994.