Pikalert® System Vehicle Data Translator (VDT) Utilizing Integrated Mobile Observations

Pikalert VDT Enhancements, Operations, & Maintenance

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The Pikalert System provides high precision road weather guidance. It assesses current weather and road conditions based on observations from connected vehicles, road weather information stations, radar, and weather model analysis fields. It also forecasts future weather and road conditions out to 72 hours utilizing information from numerical weather models.

As connected vehicle observations become more and more prevalent with the advent of autonomous vehicles, Pikalert has been designed to utilize these observations effectively. In particular, a number of quality check algorithms have been incorporated to guarantee that erroneous observations are flagged and eliminated. Pikalert then assembles the observations that have passed the quality checks, associates them with the appropriate road segments, and then uses them in assessing the road segment weather conditions. Detailed reports can then be generated characterizing the status of the various road segments assuming there is adequate connected vehicle coverage.

Pikalert advises users of the presence of three conditions (precipitation, road surface, and visibility) and will make pavement treatment recommendations for snow and ice removal. Pikalert recommendations are made available through web-based technology that supports browser-based displays and smartphones.

The software for the Pikalert System can be downloaded from the Open Source Application Development Portal (OSADP) at www.itsforge.net. Download the files associated with Pikalert-5.0 which includes the code, instructions, libraries, and sample files. The Pikalert System is a licensed open source distribution. For the good of the road weather community, any changes made to the software, particularly the algorithms, we request that any changes be deployed to the OSADP for others to use.</td></tr>
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The authors would like to thank the project stakeholder group, consisting of the following:

- FHWA Road Weather Management Program Team
- ITS JPO Data Program Team
- Minnesota Department of Transportation Integrated Mobile Observations (IMO) Project Team
- Nevada Department of Transportation IMO Project Team
- Michigan Department of Transportation IMO Project Team

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Executive Summary

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Pikalert advises users of the presence of three conditions (precipitation, road surface, and visibility) and will make pavement treatment recommendations for snow and ice removal. Pikalert guidance is made available through web-based technology that supports browser-based displays and smartphones.

Pikalert currently provides three different interfaces for users:

- Pikalert Enhanced Maintenance Decision Support System (EMDSS)
- Pikalert Motorist Advisory and Warnings (MAW)
- Pikalert MAW Phone Application

This document presents background information, an overview of the Pikalert System, state departments of transportation contributing data through Integrated Mobile Observations projects, descriptions of the Pikalert enhancements, and potential future direction of the Pikalert System.

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Chapter 1 Background

Weather has a significant impact on the operations of the nation's roadway system year round. For example, rain reduces pavement friction; winter weather can leave pavements snow-covered or icy; fog, smoke, blowing dust, heavy precipitation, and vehicle spray can restrict visibility; and flooding, snow accumulation, and wind-blown debris can cause lane obstructions.

Weather events may prompt travelers to change departure times, cancel trips, choose an alternate route, or select a different mode. Slick pavements, low visibility, and lane obstructions lead to driving at lower speeds or with increased following distances. These changes in driver behavior can impact the operation of signalized roadways, where traffic signals are timed for clear, dry conditions, through reduced traffic throughputs, increased delays, and increased travel times or disply be stuck in a traffic jam! Travel time reliability for motorists and commercial vehicle operators is affected by a variety of weather and road conditions. Adverse weather and road conditions also impacts the operational effectiveness and productivity of traffic management agencies and road maintenance agencies through increased costs and lost time.

It is, therefore, an important responsibility of traffic managers and maintenance personnel to implement operational strategies that optimize system performance by mitigating the effects of weather on the roadways. The operational approaches used by these personnel dictate their needs for weather and road condition information. Accurate, timely, route-specific weather information, allows traffic and maintenance managers to better operate and maintain roads under adverse conditions.

Connected vehicle technologies hold the promise to transform road weather management. Road weather connected vehicle applications will dramatically expand the amount of data that can be used to assess, forecast, and address the impacts that weather has on roads, vehicles, and travelers; fundamentally changing the manner in which weather-sensitive transportation system management and operations are conducted. The broad availability of road weather data from an immense fleet of mobile sources will vastly improve the ability to detect and forecast road weather and pavement conditions, and will provide the capability to manage road-weather response on specific roadway links. The FHWA Road Weather

Management Program (RWMP) has demonstrated how weather, road condition, and related vehicle data can be collected, transmitted, and used for decision making utilizing the Pikalert System.

Report Purpose

The purpose of this report is to provide a summary of the “Pikalert VDT Enhancements, Operations, and Maintenance” project including an overview of the Integrated Mobile Observations activities.

Definition of Terms

This document may contain terms, acronyms, and abbreviations that are unfamiliar to the reader. A dictionary of acronyms and abbreviations can be found in Appendix A.

Document Organization

This document is organized as follows:

Chapter 1 Background – presents a brief introduction to the report, including the report purpose, information on the definition of terms, and this document organization.

Chapter 2 Pikalert System – provides a brief overview of the IMO 2.0 project. Several other reports provide in-depth discussion of these topics, and they are referenced herein for the interested reader. A Pikalert diagram lists the various modules, with a table providing notes on each modules function.

Chapter 3 Integrated Mobile Observations (IMO) – provides a brief overview of the IMO project conducted by the Minnesota, Nevada, and Michigan departments of transportation.

Chapter 4 Pikalert Enhancements – provides information of the Pikalert enhancements deployed during this project.

Chapter 5 Pikalert Future Directions – provides a list of future enhancements possible for the Pikalert System.

Chapter 2 Pikalert System

An Overview of the Pikalert System

The purpose of the Pikalert System is to provide high precision road weather forecasts and recommendations. It assesses current weather and road conditions based on observations from connected vehicles, road weather information stations, radar, and weather model analysis fields. It also forecasts future weather and road conditions out to 72 hours utilizing information from numerical weather models.

As connected vehicle observations become more and more prevalent with the advent of autonomous vehicles, Pikalert has been designed to utilize these observations effectively. In particular, a number of quality check algorithms have been incorporated to guarantee that erroneous observations are flagged and set aside. Pikalert then assembles the observations that have passed the quality checks, associates them with the appropriate road segments, and then uses them in assessing the road segment weather conditions. Detailed reports can then be generated characterizing the status of the various road segments even when there is inadequate connected vehicle coverage.

Pikalert currently focuses on the following three conditions:

1. Precipitation conditions (such as rain, snow, ice)
2. Road surface conditions (such as snow packed, icy, clear)
3. Visibility conditions (such as foggy, clear)

Pikalert advises users of the presence of these three conditions and will make pavement treatment recommendations for snow and ice removal. Pikalert information is made available through web-based technology that supports browser-based displays and smartphones.

Pikalert currently provides three different interfaces for users:

- Pikalert EMDSS: The Pikalert EMDSS is a web-based display that provides road weather and road condition forecasts out to 72 hours. The EMDSS display is typically configured to cover a network of interstates and highways in an configured for an individual state. The EMDSS is geared toward maintenance personnel since it provides road treatment recommendations in addition to weather and road condition information.

- Pikalert MAW: The MAW display is oriented toward the public. Like the EMDSS, it provides road weather and condition information but restricts the time coverage out to 24 hours. It does not provide road treatment information, nor in depth plots of weather variables.
- Pikalert MAW Phone Application: The MAW phone app is also oriented toward the public. It supports hands-off audio alerts of hazardous road conditions up ahead. The phone app will also inform the user of clearing conditions when exiting hazardous areas.

Pikalert System Modules

The Pikalert system can be broken down into two separate subsystems:

1. A backend processing subsystem
2. A server/display subsystem

In the diagram below, Figure 1, the boxes connected by either green or blue arrows belong to the backend processing system. The boxes at the end of the purple arrows belong to the server/display subsystem.

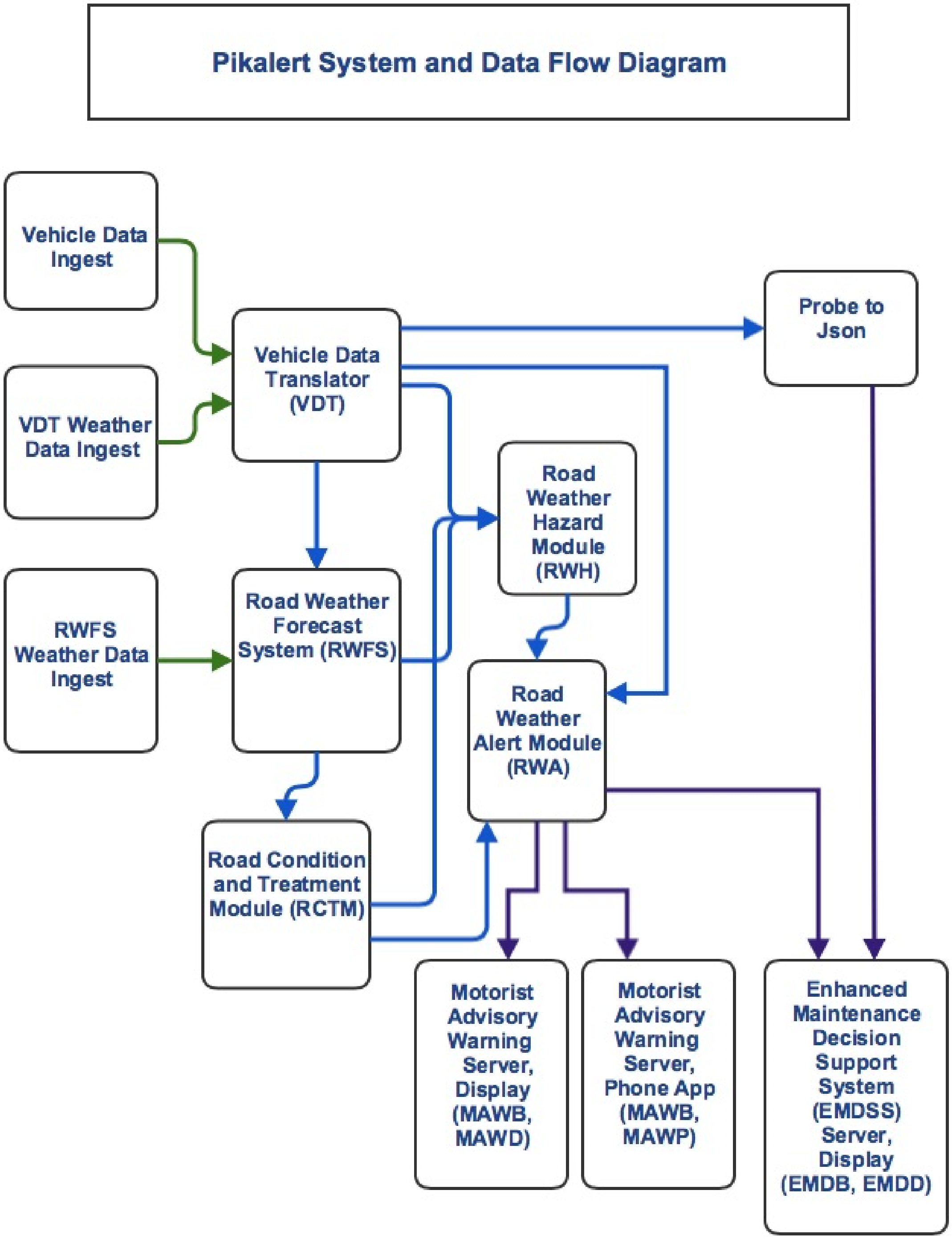


Figure 1: Pikalert Design Diagram

Backend Processing Subsystem

The backend processing subsystem is responsible for ingesting connected vehicle data and weather data, processing that data including performing data quality checks, and subsequently generating road weather diagnosis and forecast products. The backend processing subsystem consists of the following components:

- Vehicle Data Ingest
- VDT Weather Data Ingest
- RWFS Weather Data Ingest
- Vehicle Data Translator
- Road Weather Forecast System
- Road Condition and Treatment Module
- Road Weather Hazard Module
- Road Weather Alert Module
- Probe to JSON Module

Server/Display/Phone Application Subsystem

The server/display subsystem reformats the diagnosis and forecasts products created by the Pikalert backend processing subsystem and makes the reformatted products available for display or for usage in the Pikalert phone application. The server/display subsystem consists of the following components:

1. Motorist Advisory Warning Server
2. Motorist Advisory Warning Display
3. Motorist Advisory Phone Application
4. Enhanced Maintenance Decision Support System Server
5. Enhanced Maintenance Decision Support Display

Vehicle Data Ingest

In order to utilize vehicle observation data, the Pikalert System must first ingest the observation data. Typically, different states utilize different standards for formatting and providing vehicle observation data. As a result, NCAR has implemented a number of different ingest applications that have been customized for the individual IMO states.

Generally speaking, vehicle data ingest processing collects all mobile weather information provided by a state. Such data consists of Controller Area Network Bus

(CAN-Bus) data and data that comes from additional sensors that have been installed such as customized wiper or wheel rotation sensors.
After ingesting the mobile observation data, the data ingest routines typically perform a simple quality check to assess whether the data elements have valid spatial and temporal time tags. Valid data are then reformatted into a standard format for general Pikalert ingest.

Vehicle Data Translator (VDT)

The VDT ingests the formatted mobile weather observations and then performs a series of quality checks including:

1. Standard range checking to ensure mobile observations like temperature are within a reasonable range
2. Climate range checking to ensure that mobile observations are within a reasonable range given the location, month of year and time of day
3. Spatial checking comparing mobile observations with those taken at nearby RWIS stations
4. Persistence checking to determine if the mobile observation is stuck on a value
5. Time step checking to determine if the mobile observation is making an unreasonably large change
6. Model comparison checking to determine if the measurement is in general agreement with meteorological model values
7. Neighboring vehicle checking to ensure that measurements from nearby vehicles are in general agreement

The measurements that pass the quality check procedure are then used in generating statistics for road segments such as the mean air temperature at a road segment. The road segment statistics are then forwarded to the Road Weather Hazard module.

Road Weather Forecast System (RWFS)

The RWFS included in the system delivery is a simplified forecast system that uses freely-available Numerical Weather Prediction (NWP) model data to produce forecast data in a format that can be readily used by the Road Condition and Treatment Module. This particular RWFS requires only NWP data to run.

It is important to note that this RWFS can be replaced by a statistical forecasting system that uses multiple NWP models as input. In fact in running Pikalert, NCAR typically makes use of a customized statistical forecasting system based on multiple NWP input models in order to enhance Pikalert’s road weather forecast capability.

Road Weather Hazard (RWH) Module

The RWH collects road segment weather information and then performs road weather hazard assessments. It uses decision tree logic in creating assessments for three types of road weather impacts:

1. Precipitation
2. Pavement condition
3. Visibility

Precipitation

The RWH can identify three types of precipitation conditions: rain, snow, and mixed rain/snow together with three different intensities: light, moderate and heavy.

Pavement Condition

The RWH can identify the following pavement conditions:

- Dry pavement
- Wet pavement
- Snowy pavement
- Icy pavement
- Hydroplane conditions
- Slick and icy pavement
- Dry and wet pavement
- Pavement with potential ice

Visibility

The RWH can identify the following visibility conditions:

- Normal condition
- Low visibility
- Visibility impacted by heavy rain
- Visibility impacted by heavy snow
- Fog

Road Condition and Treatment Module (RCTM)

The Road Condition and Treatment Module consists of a collection of software that has been developed over many years by multiple organizations, including:

- National Center for Atmospheric Research/Research Applications Lab

- Massachusetts Institute of Technology/Lincoln Labs
- Environment Canada/Canadian Meteorological Center

Given roadway information at specific locations, a weather forecast and recent observations at those locations, the RCTM will produce a road temperature forecast as well as provide treatment recommendations at the locations.

Road Weather Alert (RWA) Module

The RWA collects data from the RWH, the RCTM and the VDT and formats that data for system output. It produces road segment alerts based on user-configured rankings and treatments, and conveys RWIS and road segment statistics for the MAW and EMDSS backend servers. The more specific information known about the roadway and maintenance rules of practice, the more precise the recommendation.

Probe to JSON

Probe to JSON is a simple module that converts the mobile connected vehicle data to JSON format to enable easy presentation by the MAW and EMDSS displays.

Motorist Advisories and Warnings (MAW)

The MAW provides motorists the capability to obtain road advisories and warnings for pre-trip planning or for making tactical decisions when on route. The MAW display application is useful for pre-trip planning and lets the motorist investigate what weather impacts are expected along potential routes over the next 24 hours.

The MAW phone application is useful for enroute travel as it warns the motorist of potential weather impacts up ahead. The MAW phone application can be used in a hands-off manner as the warnings and alerts are issued vocally.

The MAW display and phone applications require MAW server technology to provide the necessary input.

Enhanced Maintenance Decision Support System (EMDSS)

The EMDSS provides road maintenance personnel the capability to obtain road advisories, warnings, and treatment information for road maintenance purposes. The EMDSS display application covers a 72 hour forecast period and is useful for both strategic maintenance planning as well as for tactical decision-making. The EMDSS has a map-based display including radar coverage (see Figure 2). The EMDSS also allows the user to drilldown and investigate RWIS and road segment information. The drilldown capability includes RWIS camera images (see Figure 3) and RWIS weather plots (see Figure 4).

Pikalert Data Store

The Pikalert system uses the Linux file system as a data store. In particular, the outputs of the various system modules, other than the backend server modules, are all file based and stored in a directory tree. The Pikalert system is run using a set of Python scripts that execute the individual executables such as the VDT, RWH, RWA, etc. Directory information is stored in Python configuration scripts. In executing a Pikalert module, the Python scripts utilize the directory information to determine where to access the appropriate input files and in what directories to place the module's output files.

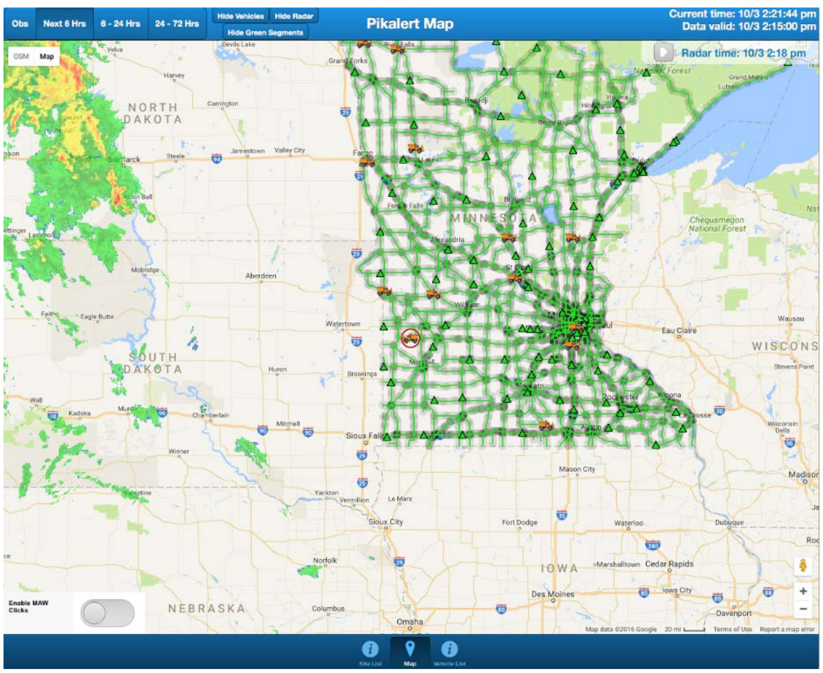


Figure 2: EMDSS Base Map Display over Minnesota

Source: Minnesota DOT.

Figure 3: Weather Camera Images at a Selected RWIS

Source: Alaska DOT.

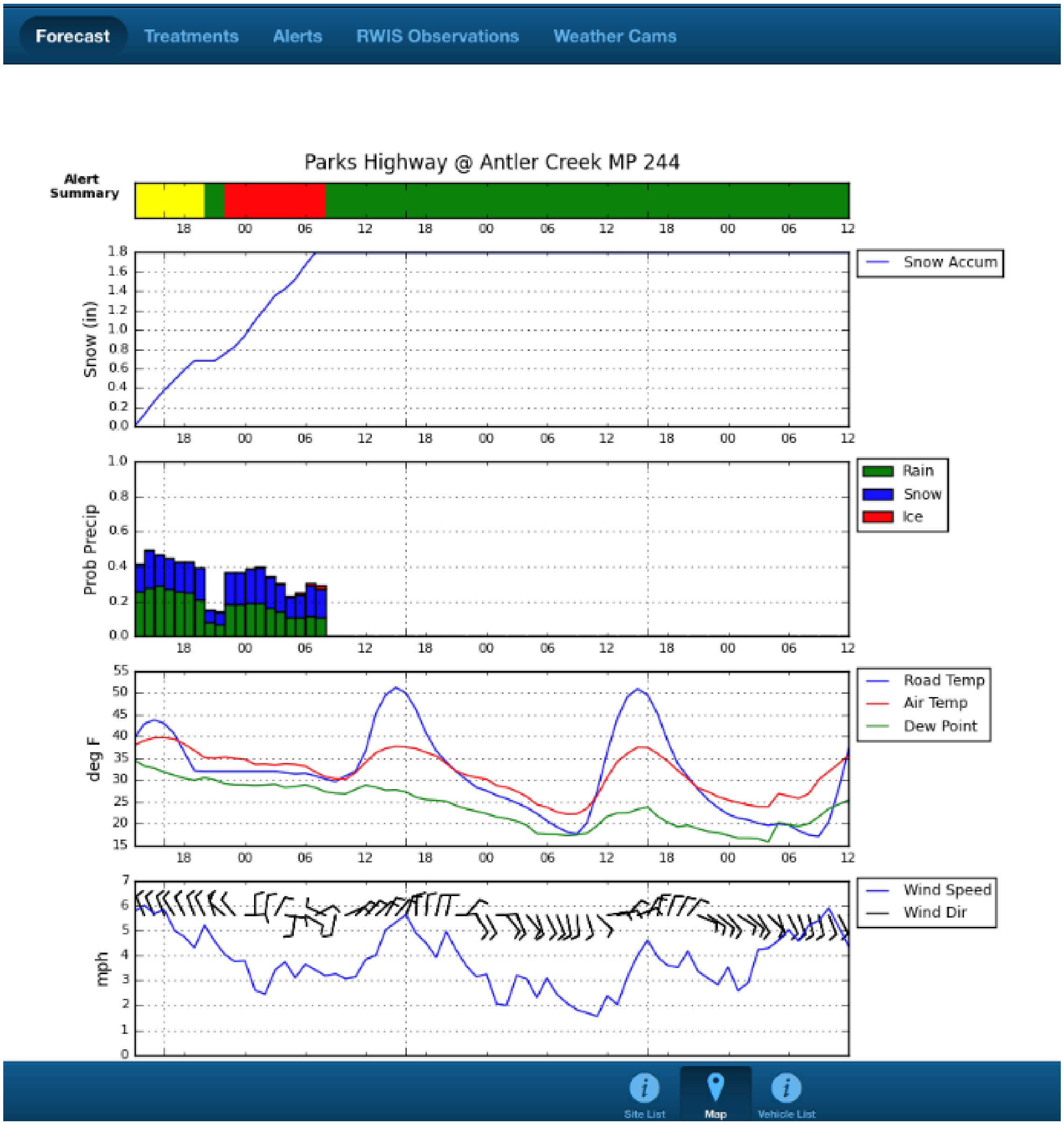


Figure 4: Weather Plots at an RWIS Station

Source: Alaska DOT.

Chapter 3 Integrated Mobile Observations (IMO)

Overview

The U.S. Department of Transportation (USDOT) Road Weather Management Program (RWMP) launched an innovative project to explore the feasibility of using vehicle-based data to support weather-related transportation safety & mobility. This project, titled Integrated Mobile Observations (IMO), examines how this data can be collected from vehicles and used to enhance decision making by traffic operators, maintenance managers, and travelers.

IMO Objectives

The USDOT established several IMO objectives:

- Better understand how to capture, communicate, and process data from the vehicle's internal codes and external road weather sensors placed on the vehicle
- Identify uses for and incorporation of the data in new and established applications
- Assess the impact and results of utilizing the data in applications

IMO Success

The project successfully achieved its objectives. Many lessons were learned and challenges were identified and overcome throughout the project. The available data has been valuable and critical for the deployment of and incorporation into applications. Some of the applications used are identified below:

- Road weather forecasts
- Traveler information
- Maintenance decision support
- End of shift reporting
- Performance management
- Material management

- Road weather conditions

Tips for Deployment Based on Lessons Learned

Working along the cutting edge means that there will be challenges and setbacks during deployment of connected vehicle technology. The state DOT project teams documented lessons learned in their final reports. Some of the tips from their lessons learned are below:

- **Establish Champions:** As important as it is to obtain high-level management champions, it is equally important to establish champions at each maintenance shed. These champions will make sure that each vehicle is configured correctly and the drivers are using the system.
- **Identify Your Needs:** With the huge amount of data available from the vehicles, it is imperative to think about and document how the agency can use the data. Bring in multiple departments and brainstorm ideas.
- **Determine Data Storage and Retention Timeframes:** The speed and storage capacities of your servers is extremely important. Determine how big they should be, how fast they need to run, and how long to keep the data. The servers will also need to feed data to other systems through streaming or file formats.
- **Select External Weather Sensors:** Based on your road weather data needs, carefully select external weather sensors for deployment. Some observation types for consideration are air temperature, surface status, relative humidity, dew point temperature, friction, and surface temperature.
- **Choose Communication Methods:** Collecting the vehicle and external sensor data requires communication at the vehicle level. Once the data is collected, then the data must be sent to the servers.
- **Install Hardware & Software on Vehicles:** Schedule installations on vehicles! If possible, upgrade software through push technology rather than requiring the presence of the vehicle.
- **Ensure System Compatibility:** Make sure that systems and software can work in unison. For instance, if you create an application for the web, make sure that your agency’s web browser is compatible.
- **Obtain FCC (& FAA, if required) License for DSRC:** As soon as you locate the desired areas for the DSRC Road Side Units (RSUs), start the process for obtaining the license. If the RSU is an FAA designated area, there are additional steps that must be accomplished before you can deploy the units.

Participating States

In order for the USDOT to achieve these objectives, the RWMP partnered with the Minnesota, Michigan, and Nevada departments of transportation. The DOTs added external weather sensors to their vehicles, created software and hardware to read the information from the vehicles and external sensors, established communication systems to send the data to servers, and incorporated the data into new and existing systems. Throughout the projects, the DOTs have gained valuable insights into the uses of the data and have transferred this knowledge to others. There have been three (3) phases of IMO – Phase 1 included the Minnesota and Nevada departments of transportations – Phases 2 and 3 included the original two with the addition of the Michigan Department of Transportation.

Phase 1 focused on identifying external road weather sensors for vehicles, determining the best communication methods, establishing a backend system to capture observations, exploring capturing CAN Bus data from maintenance vehicles, and deploying sensors on the vehicles.

Phase 2 focused on continuing and improving the deployments, evaluating the Pikalert applications, and utilizing the data collected internally within the DOT.

Phase 3 focused on continuing and improving the deployments plus adding DSRC as a communication method.

Minnesota Department of Transportation (MnDOT)

Phase 1:

- Focus Area: Statewide
- Number of Vehicles: 161 (Snowplows; Dump Trucks; & Light Duty Vehicles)
- Communication Method: Cellular and AVL
- Camera Images: Yes
- Additional Information: Extensive work was conducted to extract CAN Bus data from heavy duty vehicles

Phase 2:

- Focus Area: Statewide
- Number of Vehicles: 570 (Snowplows; Dump Trucks; & Light Duty Vehicles)
- Communication Method: Cellular and AVL
- Camera Images: Yes

- Additional Information: Equipping IMO equipment on fleet vehicles was institutionalized during Phase 2. When a vehicle is purchased and is being outfitted for add-on equipment, the IMO equipment is automatically added.

Phase 3:

- Focus Area: Statewide
- DSRC Focus Area: I-35 corridor around Minneapolis – approximately 15 miles of coverage
- Number of Vehicles: 870 (Snowplows/Sanders; Dump Trucks; & Light Duty Vehicles) – Statewide Deployment. 6 light duty vehicles for DSRC deployment.
- Communication Method: DSRC – small area; Cellular - statewide
- Camera Images: Yes
- Additional Information: Backend data servers migrated into operational servers at MnDOT; camera images being used by 511 system; vehicle data being used for reporting.

Figure 5: DSRC Equipment Installed on MnDOT Vehicle

Nevada Department of Transportation (NDOT)

Phase 1:

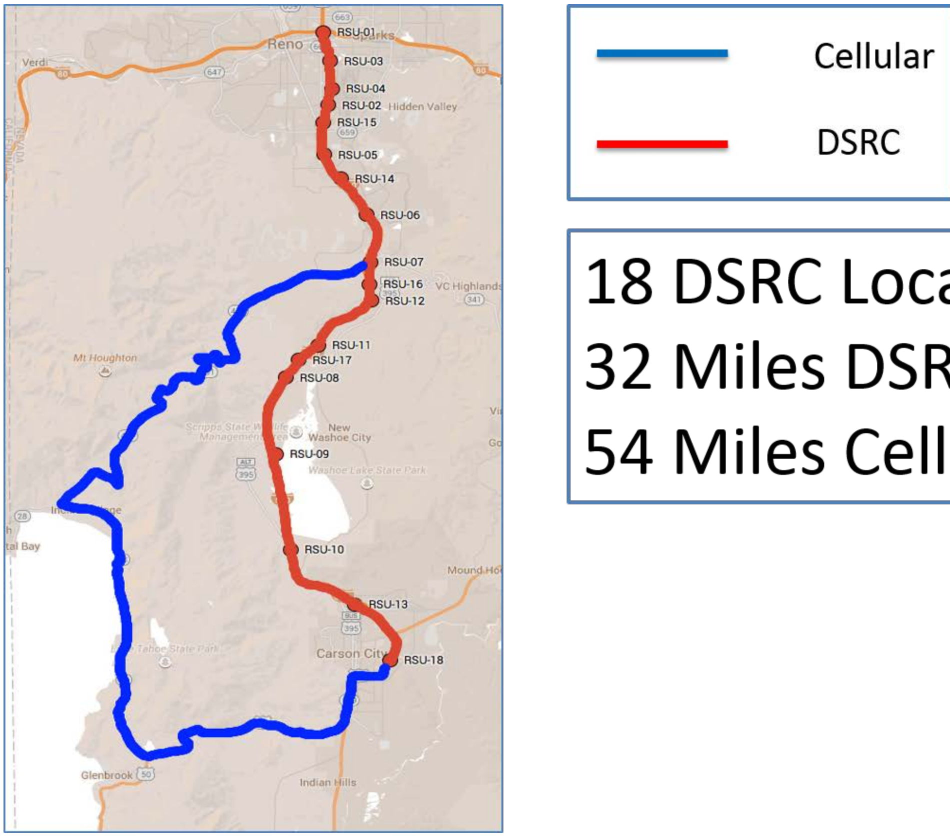
- Focus Area: I-80 corridor around Reno and Elko
- Number of Vehicles: 20 (Snowplows/Sanders; Dump Trucks; & Light Duty Vehicles)
- Communication Method: Statewide EDACS radio system (limited to 500 bytes and transmission rate of every 5 minutes) – the decision to initially deploy only EDACS was based on the rural areas selected in NV with little or no other methods available
- Camera Images: None
- Additional Information: NDOT team explored and tested multiple sensors before making final purchasing decisions.

Phase 2:

- Focus Area: I-80 corridor around Reno and Elko with emphasis on Reno area
- Number of Vehicles: 40 (Snowplows/Sanders; Dump Trucks; & Light Duty Vehicles)
- Communication Method: Cellular and Statewide EDACS radio system (limited to 500 bytes and transmission rate of every 5 minutes). Communication software configured to use cellular first – if unavailable, data sent via EDACS.
- Camera Images: Yes
- Additional Information: Began integrating data into NDOT applications

Phase 3:

- Focus Area: I-80 corridor around Reno and Elko
- DSRC Focus Area: I-580 corridor south of Reno
- Number of Vehicles: 19 (Snowplows/Sanders; Dump Trucks; & Light Duty Vehicles)
- Communication Method: DSRC, Cellular, and Statewide EDACS radio system (limited to 500 bytes and transmission rate of every 5 minutes). Communication software configured to use DSRC first – if DSRC is unavailable, use cellular – if DSRC and celluar are unaviailable, send via EDACS.
- Camera Images: Yes
- Additional Information: Backend data servers migrated into operational servers at NDOT.



18 DSRC Locations
32 Miles DSRC
54 Miles Cellular

Figure 6: Nevada DOT Phase 3 Routes

Michigan Department of Transportation (MDOT)

Phase 2: MDOT instrumented and deployed 20 snowplows and 50 light duty vehicles with connected vehicle technologies. They created a smartphone application to capture the vehicle and external sensor data via Bluetooth and transmit it via cellular communications. MDOT is using the data for road weather conditions, performance management, traveler information, and maintenance decision support.

Phase 2:

- Focus Area: I-94 corridor in southern Michigan
- Number of Vehicles: 40 fleet vehicles and 20 WMTs
- Communication Method: Cellular utilizing Bluetooth
- Camera Images: Yes
- Additional Information: Survey of drivers brought all the issues up front and helped prioritize work/issues/importance of project.

Phase 3:

- DSRC Focus Area: Saginaw Highway along M-43
- Number of Vehicles: 15 Light Duty Vehicles
- Communication Method: DSRC for Basic Safety Message (BSM) Part 1 and Cellular for weather/road weather observations
- Camera Images: Yes
- Additional Information: Incorporated data into internal data collections systems including MDSS

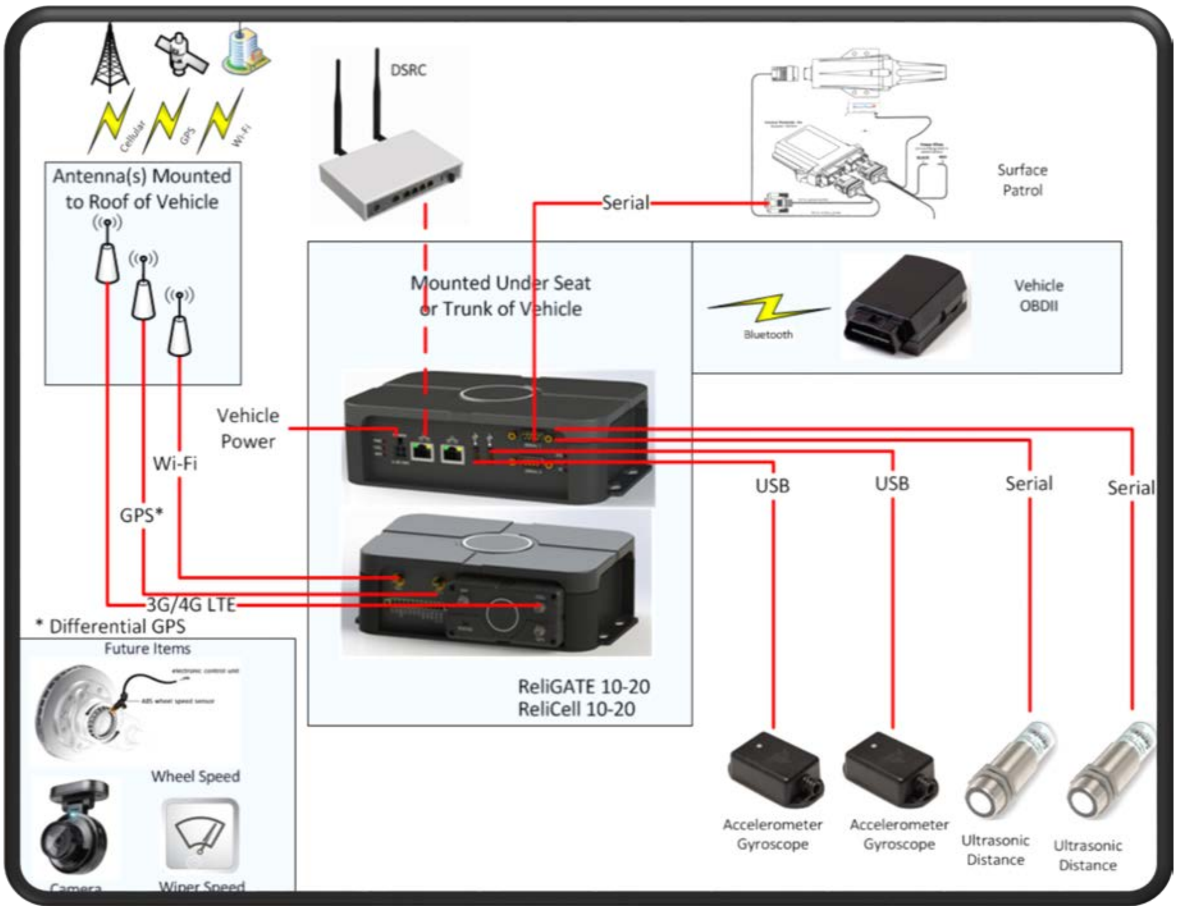


Figure 7: MDOT Phase 3 Data Collection Architecture

Chapter 4 Pikalert Enhancements

Overview

A number of science and engineering enhancements and improvements were made to the Pikalert System to promote diagnosis and forecast accuracy as well as to improve the capability of the Pikalert display. The enhancements/improvements are as follows:

Science Enhancements

- Ingest and utilize dual-polarization radar data in Pikalert
- Make improvements to the road slickness algorithm
- Improve the performance of precipitation inference in the Road Weather Hazard algorithm

Engineering Enhancements

- Incorporate Weather Telematics data in Pikalert
- Correct radar data timing on the Pikalert display
- Avoid flickering of road weather alerts
- Configure new road segments and incorporate RWIS road state fields
- Improve Pikalert display usability

The next two sections will go over these enhancements/improvements in more detail.

Science Enhancements

Ingest and utilize dual-polarization radar data in Pikalert

The goal of this enhancement was to include dual-polarization radar products in Pikalert to improve the hazard assessment capability, particularly precipitation type and intensity assessments. The following subtasks were performed:

- Ingest dual-polarization radar data into Pikalert, specifically the Hydrometeor Identification (HID) product
- Incorporate dual-polarization data in the Road Weather Hazard (RWH) module

- Perform case studies to evaluate and optimize the use of dual-polarization data

The descriptions below provide detail on how each specific subtask was addressed.

Ingest dual-polarization radar data into Pikalert, specifically the Hydrometeor Identification (HID) product

All National Weather Service (NWS) WSR-88Ds (weather radars) have been upgraded to support dual-polarization. Prior to this upgrade, horizontal reflectivity was the only radar product used in the Pikalert system. A major advantage of dual-polarization technology is that the data returned by both horizontally and vertically-polarized beams allows particle shape and composition to be inferred. This is captured in the HID product, which maps areas of snow, rain, hail, and non-precipitation echoes such as bugs or ground clutter.

While the National Severe Storms Laboratory (NSSL) provides reflectivity in a convenient mosaic used in Pikalert, other products such as the HID are not currently available in this format. Leveraging existing radar ingest capabilities at NCAR, the HID product was being read from individual radars that cover the states over which Pikalert is deployed and assigned to road segments as appropriate. This results in each road segment having both the regular radar reflectivity from the NSSL mosaic as well as a new variable containing the HID information.

Incorporate dual-polarization data in the RWH

With its ability to diagnose precipitation type, the HID product is most suited to the precipitation algorithm, where it is used to diagnose type and, in a few cases, adjust intensity. There are four main categories of precipitation type:

- Hail
- Biological/ground clutter
- Rain
- Snow

The first two types may be used without any additional logic, meaning that an HID value of Hail on a road segment will result in a Hail precipitation type, and Biological/ground clutter on a road segment will result in a No Precipitation type/intensity. For rain and snow, however, additional logic is necessary to make a final type assessment.

The lowest beam level of a WSR-88D is at 0.5 degrees elevation. This means that as the beam propagates away from the radar, its height above ground level increases. The height above ground level also depends on how the beam bends due to atmospheric density (temperature/humidity). Eventually, depending on vertical temperature profiles, the beam will cross the freezing level and while rain may be falling at the surface, the radar will be detecting snow (Figure 8). Outside of tropical zones, the most common mechanism of rain formation sees a hydrometeor start as a snow particle within a cloud, which then melts sometime after passing through the freezing level and before reaching the surface.

To most accurately account for the discrepancy between the radar-indicated hydrometeor type at beam level several meters above the surface and the actual hydrometeor type that impacts the surface, a vertical profile of temperature can be used to determine any melting and/or refreezing a particle undergoes while falling from the cloud to the surface.

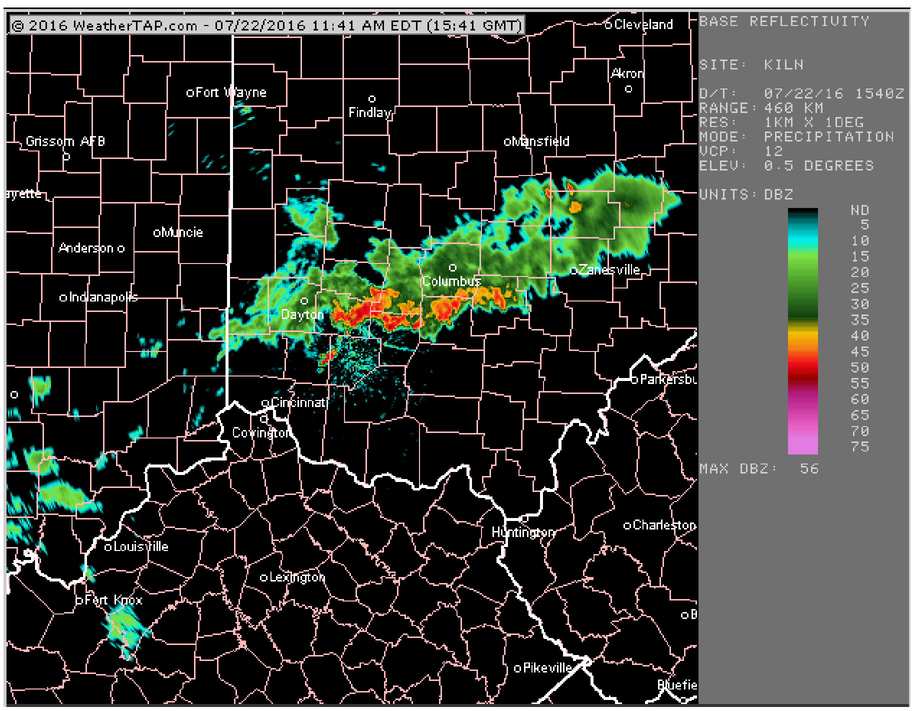


Figure 8: Thunderstorm & Rain Radar Image

Source: WeatherTap.

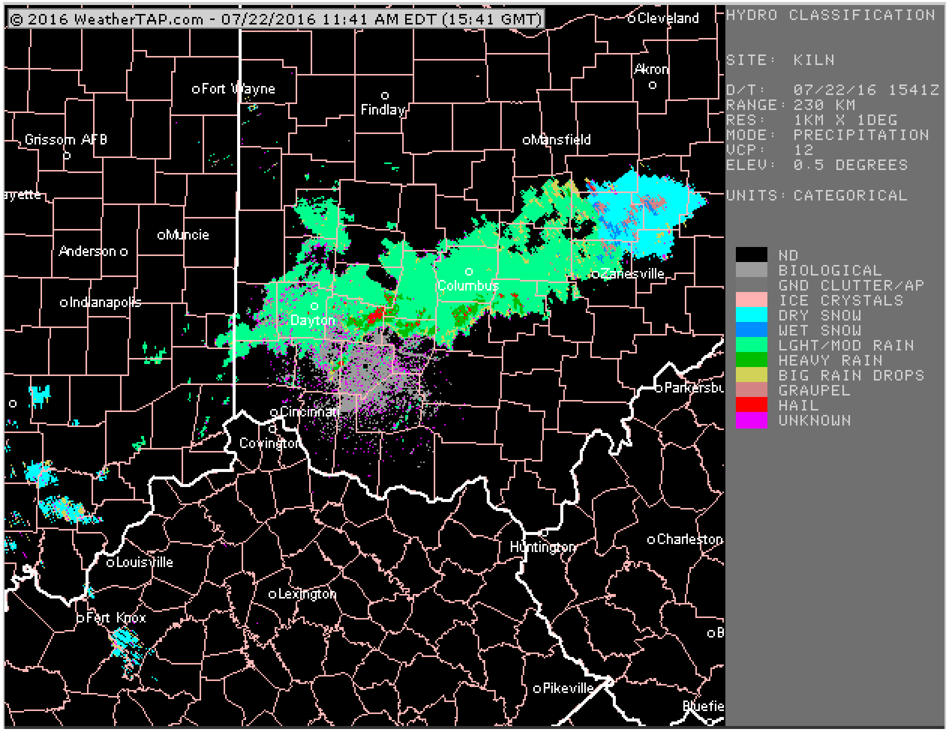


Figure 9: Dual Polarization Hydrometeor Identification

Source: WeatherTap.

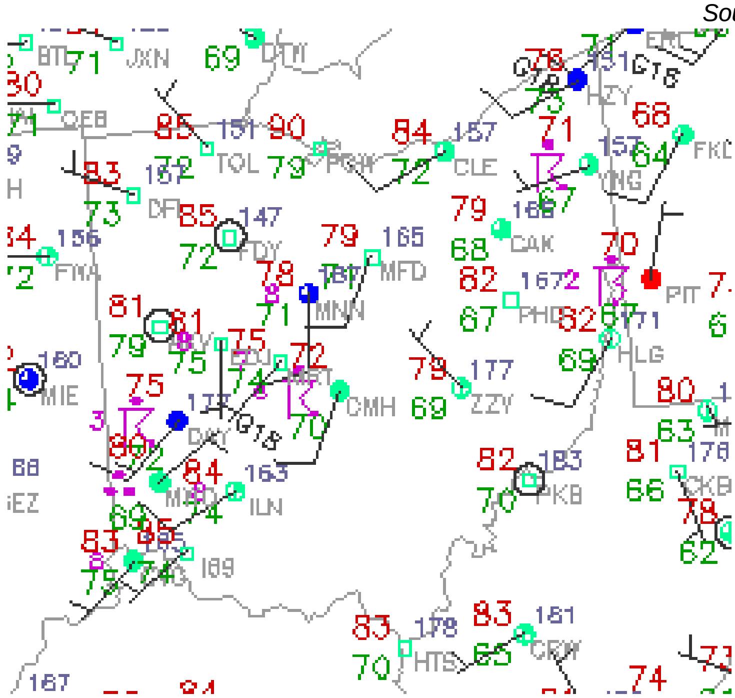


Figure 10: Temperature and Wind Plots

Source: WeatherTap.

Figure 8 is an example of the effects of the lowest radar beam increase in elevation on the HID product. It shows a base reflectivity image containing thunderstorms and rain, while the Figure 9 shows the HID product with rain in greens and snow in blues. The far right portion of the rain has been identified as snow due to the radar beam shooting through the freezing level, while surface temperatures and observations (Figure 10) show rain is occurring at the surface, not snow.

Using only surface temperature, rather than a vertical profile, avoids significant re-engineering of the VDT and RWH modules while providing sufficient information to translate a hydrometeor type from cloud level to the surface. A value of 1 degree C was used to differentiate between rain and snow at the surface when snow is identified by the HID aloft, while a value of 0 degrees C was used to determine if rain or freezing rain was occurring at the surface when rain is identified by the HID aloft.

Perform case studies to evaluate and optimize the use of dual-polarization data

Case studies aided both development and testing of the new HID precipitation type logic. This included determining if using only a surface temperature vs. a vertical profile of temperature caused major detriments to precipitation identification. Four cases were used:

- 17 Mar 2014: A freezing rain case in the Minneapolis/St. Paul, MN area
- 19 Feb 2016: A rain case over Boulder, CO where the HID precipitation types were predominately snow
- 23 Feb 2016: A rain to snow transition case along the Front Range of CO
- 23 Mar 2016: A major snow event along the Front Range of CO that started with light to moderate rainfall

The first case addressed issues with diagnosing freezing rain/sleet conditions from the HID product. In general, rain aloft and a below freezing surface temperature was sufficient to distinguish areas with freezing rain from areas with snow, where the HID identification aloft was also for snow.

The second case was used to determine if the RWH logic was sufficiently able to identify a rainfall event despite the radar seeing above the freezing level and the HID product indicating snow aloft while there was rain at the surface.

The third case went a step further than the second in that while there was originally rainfall at the surface, this eventually changed into snow as the event progressed. This was used to help determine the best surface temperature criteria for distinguishing between rain and snow with snow aloft and allowing the algorithm to properly detect the rain to snow transition. This more sophisticated logic compared to the -2 to 2 degrees C “mixed precipitation” indication used in the previous version should provide more accurate precipitation typing when temperatures are near the freezing level.

The fourth case served as another check of the algorithm’s ability to distinguish between rain and snow, including a rain to snow transition as the event progressed.

In all four cases, the algorithm performed quite well at the surface observation sites selected, with a less than 15-minute lag in identifying a rain to snow transition.

Make Improvements to the Road Slickness Algorithm

The goal of this task was to examine the road slickness algorithm, a part of the road condition algorithm in the RWH, and determine how it was performing and if any updates should be made. Potential actions proposed for this task were:

- Identify false alarms and possible corrections to those
- Add road frost as a potential indicator of slick roads
- Utilize mobile data, road temperature, and relative humidity data in making improvements
- If time and budget allows, incorporate Nevada’s road slickness work

The descriptions below give detail on how each specific subtask was addressed.

Identify false alarms and possible corrections to those

Case studies were identified and analyzed from the Integrated Mobile Observations (IMO) states to determine how well the slickness algorithm performed. The cases studies included both missed slick roads and false alarms for slick roads. The slick road conditions were compared to Road Weather Information System (RWIS) station observations of road conditions along with input provided by local personnel. Many of the cases occurred before other enhancements were made to the Road Weather Hazard Module (RWH) that would directly impact the slickness assessments. Improvements made include:

- Dew point depression: added dew point depressionto the precipitation algorithm to reduce precipitation false alarms

- Pavement persistence: allows snow/ice on the pavement to persist past the end of falling precipitation.

- Statonary Vehicles: many errors occurred when using data from vehicles that were not moving. These vehicles often gave erroneous data, though the data was within the quality check tolerances enough to be passed to the RWH. To correct this, the Data Filtering Test was updated to include a parameter to flag as bad data from vehicles with zero speed. This is entirely user configurable.

- Null Value: Another data input update involved values of zero. Many partners that provide data to the VDT appear to use zero as a missing value. This is problematic as zero is often a valid meteorological value for certain variables, so it will not be flagged as bad by the quality check tests in many situations when it is actually a missing value. Data providers have been reluctant to use a more appropriate missing value such as -9999, so the option was added to the VDT to flag as bad incoming values of 0. This is applied to the raw data rather than probe message data. For example, an incoming value of 0.0 F should be flagged as bad quality, but in the probe message it is converted to -17 C. Therefore, the test must be applied to the value before it is converted to the units used by the VDT.

Add road frost as a potential indicator of slick roads

The current road frost predictor used in the MDSS was examined for potential applicability to the RWH pavement condition algorithm. After discussion about the skill of the existing road frost algorithm and the small impacts of road frost on pavement slickness, it was determined that adding the road frost algorithm to the RWH would not be a good use of resources at this time.

Utilize mobile data, road temperature, and relative humidity data in making improvements

a. Mobile data

   During the case studies discussed in subtask 1 above, additional mobile data were considered for use in the slickness algorithm. After examining mobile data available for the cases and comparing them to conditions and what data types were being used/not being used, it was determined that there were no existing additional mobile data that would be useful to add to the slickness algorithm at this time. However, work was done to make sure all available mobile variables used in the algorithm (e.g., ABS status) were being properly read into and used by the Pikalert system.

b. Road temperature

After examining the cases described in subtask 1 above, it was decided that the use of road temperature in the pavement condition assignment was sufficient and there was no need to double-use this variable in the slickness assessment portion of the algorithm.

c. Relative humidity

From case study analysis it was decided there would be no value added to the algorithms by using this variable at this time. However, through future examination of RWH performance, this variable may be useful for the pavement persistence portion of the road condition algorithm.

Improve the Performance of Precipitation Inference in the Road Weather Hazard Algorithm

Although improvements to the frequency of precipitation false alarms had been made in the past, additional work was necessary to further reduce the amount of false alarms. Specific tasks under this enhancement were:

- Add dew point depression to the precipitation intensity inference algorithm
- Use composite reflectivity where base reflectivity is not available or blocked
- Integrate relevant short term forecast precipitation data when radar and mobile data are not available

The descriptions below give detail on how each specific task was addressed.

Add dew point depression to the precipitation intensity inference algorithm

Dew point depression is defined as the difference between the ambient air temperature and the dew point temperature ($T – T_d$). This gives a quick, easy to calculate measure of atmospheric moisture. When the dew point depression is low, the air is more saturated, and when the dew point depression is high, the air is drier.

In some areas, such as Nevada, virga, precipitation evaporating before reaching the ground, is a common phenomenon. Without ground observations such as RWIS stations or mobile vehicle observations, the radar at its lowest level will see the precipitation and produce a false alarm. This is also common in areas that are further away from nearby radars, such as southwest Minnesota.

The dew point depression can be used to correct for both the above cases. Virga occurs in areas of high dew point depression/low humidity, and a higher dew point depression can also indicate that precipitation the radar has detected far away (so higher above ground) is likely not reaching the surface.

After performing case studies on data from IMO states, two levels of dew point depression adjustments were identified. For a dew point depression between 4 and 10°C, precipitation intensity assessed by the radar reflectivity is adjusted down one level (e.g., “moderate” intensity is reduced to “low”). For a dew point depression greater than 10°C, both “light” and “moderate” intensities are reduced to “none”, while a “heavy” intensity is reduced to “moderate”. The adjustment is performed after the radar data have been processed but before adjustments are made with mobile data, so that the mobile data may correct the precipitation inference as required and make a differentiation between precipitation falling and road splash.

Use composite reflectivity where base reflectivity is not available or blocked

A major precipitation detection issue in complex terrain such as Nevada is that the terrain blocks the radar beam, resulting in unobservable areas.

In the absence of mobile data or other surface sensors, an area of blocked radar coverage cannot be sampled to give a precipitation inference. A further complication is that to the radar, such areas simply appear to have no precipitation rather than to be blocked. Information about beam blockage is not available in the suite of products from the National Weather Service (NWS), and the calculation of beam propagation (and thus whether a beam is blocked) is not only a function of beam azimuth and elevation angle, but also the atmospheric conditions such as temperature and moisture.

Due to the lack of available beam blockage products and the difficulty of calculating beam propagation and blockage, the original plan to use composite reflectivity in blocked areas involved a lot of work. However, an additional radar reflectivity product is available from the NWS called the Hybrid Scan Reflectivity. To produce this product, an algorithm determines the degree to which a beam is blocked at each range gate (or “pixel”). If blockage is 10%-50%, reflectivity from surrounding gates is used to fill in the blocked gate. If blockage is >50%, then the next highest elevation angle is used. If that elevation angle is also blocked >50%, the next highest is used, and so on.

Because the Hybrid Scan Reflectivity achieves the same goal as using composite reflectivity in areas where base reflectivity is blocked, but also performs the blocking calculation before reaching the VDT, this product replaced the base reflectivity being used previously in the Pikalert system and adding composite reflectivity was not necessary.

While this radar product improved coverage over a lot of the complex terrain areas, some areas still cannot be seen due to overshooting of the radar beam. This means that the lowest radar level that is not blocked passes above where the precipitation is occurring further away, past the blockage area.

Integrate relevant short term forecast precipitation data when radar and mobile data are not available

Previous updates to the system and the two enhancements above added to the coverage of the RWH and its ability to make current condition inferences in a variety of locations, such as complex terrain. However, because some areas are still inaccessible to radar coverage that also may not have fixed station or mobile data present, the lack of data must be addressed.

To this end, using the model data to supplement these areas was explored. Model data has the advantage of total coverage in all areas. However, it has several disadvantages in this particular case, including:

- Supplementing the observed condition assessment with a model assessment is not consistent with the structure of the RWH, where current conditions are presented as observed weather and only future conditions are presented as model forecasts
- Model timing of system location (i.e., when precipitation begins and ends on a given road segment) may be off by one to several hours, which would result in an erroneous assessed or “observed” condition that is not consistent with true conditions or surrounding areas with sufficient observed data
- Observing vehicles moving in and out of a location could result in flickering of alerts on a given segment if the model data is not consistent with the vehicle-observed weather
- The difficulty of modeling the atmosphere in complex terrain, where the majority of beam blockage and missing ground data occurs, contributes to

errors in the model that are acceptable as part of a 1+ hour forecast but not acceptable to present as the currently observed weather

Because the current time assessments are assumed to be based on observations, along with the other reasons given above, it was decided that this enhancement would not be good for the RWH.

Without this enhancement, there is still an issue of insufficient data to make an inference, in particular in areas of radar beam blockage (see #2 above) where the area simply appears devoid of precipitation to the radar. To address this, updates were made to the RWH and RWA modules to indicate whether enough data are available to make an observed inference, or if only the forecast may be used. On the display, segments without enough data to make an inference may be colored “gray” for the current time, and the forecasted conditions are still presented as usual.

While data sparse regions are currently an issue, with time as more connected vehicles come on line these areas will be filled in with data from these vehicles. Data sparse/rural areas have huge potential for benefit from connected vehicle observations as the program progresses.

In addition to the three above enhancements, two other enhancements related to other tasks have an additional benefit for the precipitation algorithm:

1. Adding surface station (ASOS and RWIS) present weather observations of precipitation and intensity as a cross check to the RWH-assessed precipitation type and intensity
2. Setting precipitation intensity thresholds based on air temperature, rather than season (winter vs. summer), to cover conditions where rain may occur in winter and snow may occur in autumn, spring, or summer.

Engineering Enhancements

Incorporate Weather Telematics Data in Pikalert

Weather Telematics is a company that has equipped over 1500 vehicles with weather sensors that can collect the following:

- temperature,
- rain
- light
- relative humidity
- pressure
- dew point temperature

Using telematics technology, Weather Telematics then conveys the observed data to a central hub for distribution to clients. In March 2016, NCAR implemented ingest software to access the Weather Telematics data through the Federal Highways Weather Data Environment (WxDE). NCAR then integrated the Weather Telematics data into Pikalert. The Weather Telematics observations gathered in Michigan, Minnesota, and Nevada are now being utilized in assessing current road weather conditions for those states.

Correct Radar Data Timing on the Pikalert Display

When panning and zooming the Pikalert display, the radar images were not being updated properly. In particular, old radar data could be rendered with new radar data. In this enhancement, the timing problem was corrected. In addition, radar movie loop capability was installed in the Pikalert display. Figure 8 over Nevada illustrates the radar image capability in Pikalert.

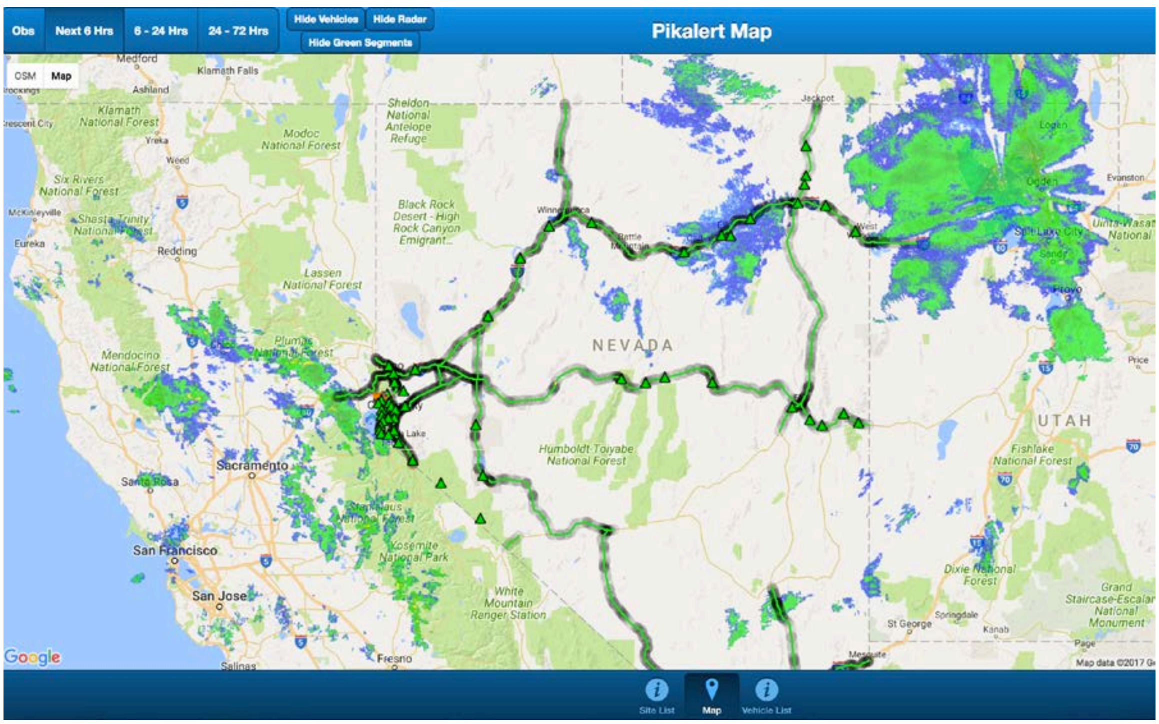


Figure 11: New Road Segments Implemented in Nevada

Avoid Flickering of Road Weather Alerts

Alerts or alarms that cycle between on and off over short periods of time can easily end up being a nuisance to users and lead to a lack of trust in the alerts and subsequent abandonment. To avoid such alert cycling, the Pikalert system now holds an alert for a configurable minimum period of time before allowing the alert to disappear. For example, instead of allowing an alert to switch from on and off every five minutes, an alert condition such as blowing snow is held for at least 15 minutes before switching to a less impactful level.

Configure New Road Segments and Incorporate RWIS Road State Fields

The DOT's in both Minnesota and Nevada wanted to extend Pikalert coverage to include a wider network of interstates and highways. NCAR worked with both states obtaining new road shapefiles and then configured the Minnesota and Nevada Pikalert systems using the new extracted road information. The Pikalert road coverage in both Minnesota and Nevada has now been significantly improved (see Figures 2 and 11).

RWIS stations may provide a road state field, which when accurate, is helpful in diagnosing road conditions. RWIS road state information can address the following:

- No report
- Dry
- Moist
- Moist and chemically treated
- Wet
- Wet and chemically treated
- Ice
- Frost
- Snow
- Snow/Ice Watch
- Snow/Ice Warning
- Wet Above Freezing
- Wet Below Freezing
- Absorption
- Absorption at Dew point
- Dew
- Black Ice Warning
- Other

- Slush

As part of this enhancement, Pikalert now incorporates RWIS road state information in the VDT and the road weather hazard algorithm for enhancing the current diagnosis of road weather conditions.

Improve Pikalert Display Usability

On January 6, 2016, Microsoft stopped support Internet Explorer 8, 9, and 10. One of the key tasks in this enhancement was to ensure that the Pikalert display works properly when using Internet Explorer 11. NCAR made changes to the display software to support IE 11. NCAR also checked that the Pikalert display works on other browser technology such as Chrome, Firefox, and Safari.

NCAR made additional display enhancements such as:

1. Added RWIS Weather Camera imagery to RWIS inspection
2. Added Dual Polarization information to the Road Segment Observations
3. Included additional fields such as number of wipers on/off to Road Segment Observations

Chapter 5 Pikalert Future Directions

Overview

The Pikalert system employs a novel approach of utilizing connected vehicle observations in diagnosing and forecasting significant road weather events affecting motorists and road maintenance personnel. In working with FHWA and the IMO states, a number of areas have been identified where the Pikalert technology can be advanced.

Enhancing Treatment Recommendations

The Pikalert system currently utilizes the METRo physical model from Environment Canada for making road temperature and road condition forecasts. Like most models, METRo has its strengths and weaknesses. In particular, METRo was designed for diagnosing and forecasting winter road conditions and tends to forecast temperatures that are hotter than observed during the summer. METRo also has a number of inefficiencies that make it difficult to utilize at an extensive number of sites. Making improvements to the summer road temperature modeling in METRo is one area that would benefit the utility of Pikalert's forecast for year-around use.

A road treatment statistical model could also provide benefit in this area especially if sufficient ground truth observations are available. Machine learning techniques can be applied correlating recent meteorological observations, traffic, plowing, and chemical application information to diagnose/forecast road conditions.

Include RWIS Camera Image Processing

NCAR is currently performing work in the automatic recognition of different types of weather in static camera images taken at RWIS stations. Identifying winter weather, precipitation, and low visibility weather events would improve Pikalert's diagnostic capability.

Enhance Radar Capability

NCAR researchers have discovered a number of cases where radar echoes are not in agreement with the weather experienced on the ground as can be gleaned from RWIS camera images. Here the radar indication would be automatically tuned using information from the above description of RWIS Camera Image Processing.

Include shading in road segment information

The inclusion of shading information would lead to improved road condition and treatment forecasts particularly in areas subject to shading. This work would take into account terrain, date, and time of day, and solar angle. Areas subject to shading that have deposited snow and are not plowed would be expected to have longer periods of snow coverage.

Improve Pikalert's Web Display Capability to Handle Dense Road Networks

The current display technology used in Pikalert has noticeable load issues when handling dense road networks consisting of millions of latitude-longitude points. The NCAR Pikalert team is currently investigating different technologies that would allow states to effectively handle such dense networks.

Utilize WRF Model for Improved Road Prediction of Snow/Ice

Researchers at NCAR have made improvements to the WRF model with regard to snow and ice prediction. Incorporating recent advances in the WRF model in Pikalert would potentially aid in improved winter weather prediction capability.

Include Weather Alert Notification Capability

Pikalert has a web-based display that illustrates current and forecasted road conditions. When weather conditions are quickly changing it would be helpful for users to be notified of significant weather events depending on their notification interests. For example, users could register their interest in moderate to heavy snow events and then receive email notifications of event times and locations.

Incorporate Travel Time Capability Informed by Weather Forecasts

Current travel time estimates typically do not incorporate forecasted weather. For example, a severe winter storm predicted 30 minutes from now is usually not factored into most travel time products. Accurate travel times during winter weather events need to factor in weather-related slowdowns and accidents.

Provide Route Planning Capability that Incorporates Weather Forecasts

A number of companies now offer route-planning capability that incorporates current traffic information, along with construction, road closure, and detour information. Such products would be improved with the use of forecasted weather especially during winter weather events for longer road trips.

Enhance Pikalert Phone Application

The Pikalert Phone App currently warns the driver if his or her vehicle is approaching an area where hazardous weather has been diagnosed. Incorporating traffic, construction, accident, and travel time information will make the phone app more useful. The Pikalert Phone App can also be modified to support maintenance personnel by making road condition information available.

Create Dashboard Displays Presenting Vehicle Data and Sensor Information

A dashboard display presenting recent vehicle data including location information along with sensor quality check status information would be useful for maintenance personnel.

Port MAW Phone Application to the iPhone

The MAW Phone Application was developed using the Android Operating System. Porting the phone application to the iPhone would make the phone application available to a wider audience.

Utilize a Moving Maps Display in the Phone Application

New software toolkits support the creation of moving maps displays. Adding a moving maps display would be helpful for hands-off viewing of vehicle location with regard to winter weather.

APPENDIX A. References

Anderson, A. R. S., G. Wiener, S. Linden, W. Petzke, G. N. Guevara, B. C. Boyce, and P. Pisano, 2016: The Pikalert® Vehicle Data Translator – Updates and applications. 32nd Conf. on Environmental Information Processing Technologies, New Orleans, LA, Amer. Meteor. Soc., 11B.4. [Available online at https://ams.confex.com/ams/96Annual/webprogram/Paper287458.html.]

Anderson, A.R.S., S.D. Drobot, M. Chapman, G. Wiener, B. Lambi, P. Pisano, G.N. Guevara, 2012: Development of algorithms to determine precipitation, pavement condition, and visibility hazards along roadways using mobile observations. 28th Conf. on Interactive Information Processing Systems (IIPS), New Orleans, LA, Amer. Meteor. Soc., 11B.4.

Kanamitsu, Masao, Wesley Ebisuzaki, Jack Woollen, Shi-Keng Yang, J. J. Hnilo, M. Fiorino, G. L. Potter, 2002: NCEP–DOE AMIP-II Reanalysis (R-2). *Bulletin of the American Meteorological Society*. 83:1631–1643. doi: http://dx.doi.org/10.1175/BAMS-83-11-1631

Park, H., A. V. Ryzhkov, D. S. Zrnić, K.-E. Kim, 2009: The hydrometeor classification algorithm for the polarimetric WSR-88D: Description and application to an MCS. *Wea. Forecasting*, **24,** 730-748.

National Center for Atmospheric Research (NCAR), 2009a: Vehicle Standards. 17pp.

NCAR, 2009b: Post-Demonstration Analysis. 64pp.

NCAR, 2012: Application Selection Report. 11pp.

NCAR, 2014a: Enhanced Maintenance and Decision Support System - Detailed System Requirements. 42pp.

NCAR, 2014b: Motorist Alert and Warning Application - Detailed System Requirements. 45pp.

NCAR, 2014c: Enhanced MDSS and Motorist Advisory and Warning Applications System Design Description. 103pp.

NCAR, 2014d: The Enhanced Maintenance and Decision Support System: User Guide. 21pp.

NCAR, 2014e: The Motorist Advisory and Warning System: User Guide. 16pp.

NCAR, 2014f: Applications Test Strategy. 14pp.

APPENDIX B. List of Acronyms

Acronym	Definition
ABS	Anti-lock Braking Status
AVL	Automatic Vehicle Location
ASOS	Automated Surface Observing System
BAH	Booz Allen Hamilton
CAN-Bus	Controller Area Network Bus
EMDB	Enhanced Maintenance Decision Backend
EMDD	Enhanced Maintenance Decision Display
EMDSS	Enhanced Maintenance Decision Support System
FHWA	Federal Highways Safety Administration
HID	Hydrometeor Identification
IMO	Integrated Mobile Observations
JSON	JavaScript Object Notation
MAW	Motorist Alert and Warning
MAWB	Motorist Alert and Warning Backend
MAWD	Motorist Alert and Warning Display
MAWP	Motorist Alert and Warning Phone
MDOT	Michigan Department of Transportation
MDSS	Maintenance Decision Support System
METRo	Model of the Environment and Temperature of Roads
MnDOT	Minnesota Department of Transportation
NCAR	National Center for Atmospheric Research
NWS	National Weather Service
RCTM	Road Condition and Treatment Module
RWA	Road Weather Alert
RWFS	Road Weather Forecasting System
RWH	Road Weather Hazard
RWIS	Road Weather Information System
UNR	University of Nevada at Reno
USDOT	United States Department of Transportation
VDT	Vehicle Data Translator

Acronym	Definition
WSR-88D	Weather Surface Radar, 1988 Doppler

APPENDIX C. Weather Sensor Recommendations for CAMP

During the course of the Pikalert projects, we have worked directly with the Crash Avoidance Metrics Partnership (CAMP) – a consortium of automakers – to help them understand the difference between weather (the atmospheric and precipitation conditions) and road weather (how the weather affects the roadways); the activities occurring within the Road Weather community; and the research conducted to determine a prioritized list of vehicle observations that would enhance road weather applications.

Table 1 describes the observations from the vehicle that would enhance road weather applications. Each observation type (variable) is prioritized and shows the unit, resolution, accuracy, and frequency parameters. The information in the table was determined over a five (5) year timeframe utilizing real-time mobile observations and psudo observations.

Table 1: Observations Desired from Vehicles for Road Weather Applications

Priority	Variable	Unit	Desired Resolution	Acceptable Resolution	Desired Accuracy	Acceptable Accuracy	Desired Frequency	Acceptable Frequency
1	Air Temperature	Celsius	0.1 degree	1 degree	1 degree	3 degrees	once per 10 seconds	once per minute
2	Wiper Status	None	off, on, low, medium, high, intermittent speeds	off, on	correct category	correct category	once per 10 seconds	once per minute

Priority	Variable	Unit	Desired Resolution	Acceptable Resolution	Desired Accuracy	Acceptable Accuracy	Desired Frequency	Acceptable Frequency
3	Surface Temperature	Celsius	0.1 degree	1 degree	1 degree	3 degrees	once per 10 seconds	once per minute
4	ABS Brake Status	None	off, on	off, on	correct category	correct category	event driven	event driven
5	Dew point Temperature	Celsius	0.1 degree	1 degree	1 degree	3 degrees	once per 10 seconds	once per minute
6	Traction Control active	None	off, on	off, on	correct category	correct category	event driven	event driven
7	Stability Control active	None	off, on	off, on	correct category	correct category	event driven	event driven
8	Wheel Rotational Displacement	Revolutions per second	0.01 revolution per second	0.1 revolution per second	0.01 revolution per second	0.1 revolution per second	once per second	once per 10 seconds
9	Precipitation sensor	None	off, on (is there something else?)	off, on	correct category	correct category	once per 10 seconds	once per minute
10	Atmospheric Pressure	HectoPascals (hPa)	0.1 hPa	5 hPa	1 hPa	5 hPa	once per 10 seconds	once per minute

Priority	Variable	Unit	Desired Resolution	Acceptable Resolution	Desired Accuracy	Acceptable Accuracy	Desired Frequency	Acceptable Frequency
11	Lights	None	off, on for low beams, on for high beams, on for fog lights	off, on	correct category for different types of lights	correct category	once per 10 seconds	once per minute
12	Yaw	Angle						
13	Pitch	Angle						
14	Solar Radiation	Watts per meter squared	1 w/m^2	10 w/m^2	5 w/m^2	10 w/m^2	once per 10 seconds	once per minute
15	Total Radiation	Watts per meter squared	1 w/m^2	10 w/m^2	5 w/m^2	10 w/m^2	once per 10 seconds	once per minute

APPENDIX D. Quality Checks & Road Weather Hazard Assessment

Quality Checks

The Pikalert System performs a series of quality checks on mobile observations prior to using them in any algorithms. The steps below give an overview of the quality checks and Figure 8 demonstrates how the flow of observations occur in the VDT including the quality checks.

1. First, messages with missing or bad latitude/longitude or observation time that is outside the time interval of interest are filtered out
2. Standard qc checks
3. Sensor range test ensures that sensor measurements are within a configurable range
4. Climatological range test ensures that sensor measurements at a location are within climatological min and max values at that location
5. Spatial checks ensure that measurements are close to those of nearby RWIS stations
6. History checks
7. Step test ensures that sensor measurements are not making unreasonable changes in magnitude over short time periods
8. Persistence tests check that sensor measurements are not stuck on a value
9. Combined checks
10. The combined check is applied after the standard range test. I.e., if a measurement falls outside the standard range, it cannot pass the combined check test.

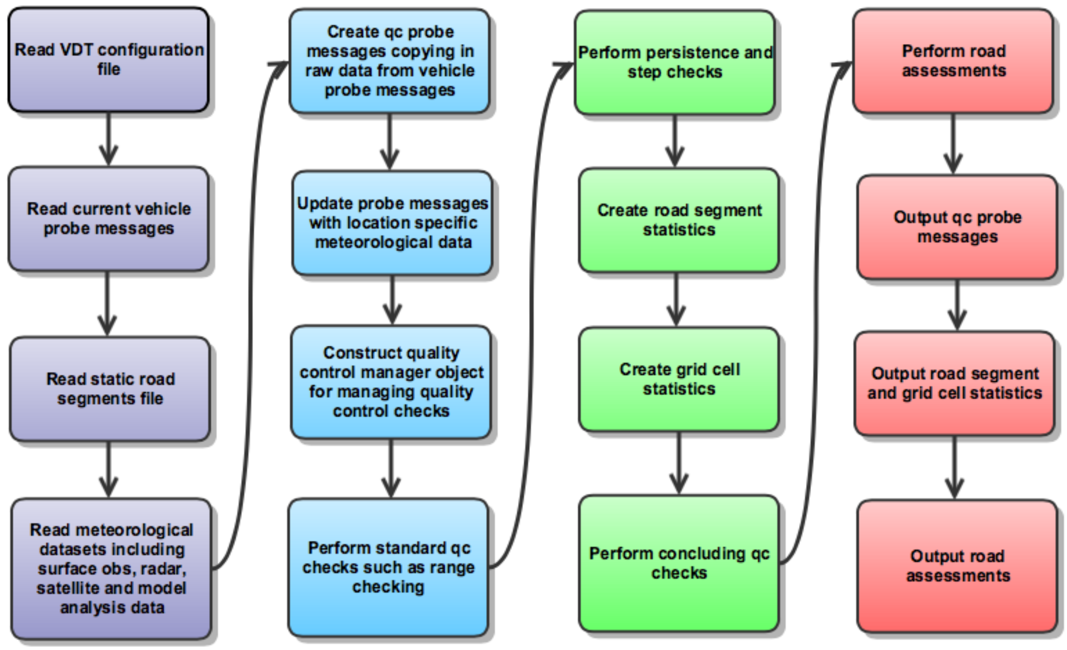


Figure 12: VDT Processing Steps including Quality Checks

Road Weather Hazard Assessment

The Road Weather Hazard Assessment Module collects the segment statistics files output by the VDT at each time period, the output files from the Road Weather Forecast System atmospheric forecast and the Road Condition and Treatment Module road condition forecasts. The RWH then reads in its configuration file, forecast site list, and VDT road segments. The RWH pulls out the required variables from the VDT segment statistics files and organizes them by road segment. The RWH also pulls out the required variables from the RWFS and RCTM files and organizes them by forecast site and lead time.

The RWH ingests the VDT segment statistics variables and performs the assessment on each road segment. The assessments that are performed are the following:

- Precipitation type
- Precipitation intensity
- Pavement condition
- Slickness flag
- Visibility

The RWH holds the resulting tactical assessments while the forecast assessments are run. The RWH then ingests the RWFS and RCTM variables and performs the assessment at each forecast site and for each lead time. The assessments that are performed match those listed above.

The tactical and forecast hazard assessments are matched together using the road segments and forecast site list and the RWH writes out the hazard assessments in one Network Common Data Form (netCDF) file containing the following:

- Time
- Road segment ID
- Precipitation type – Rain, Snow, Mix
- Precipitation intensity – None, Light, Moderate, Heavy, Road splash
- Road condition – Dry, Wet, Snow covered, Ice covered, Hydroplane potential Black ice, Dry/Wet, Ice possible
- Slickness flag - Not slick, Slick
- Visibility – Normal, Low, Heavy Rain, Heavy Snow, Blowing Snow, Fog

U.S. Department of Transportation
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