# Integration of Aviation Automated Weather Observation Systems (AWOS) with Roadside Weather Information Systems (RWIS)

## Final Report

by


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# EXECUTIVE SUMMARY

The California Department of Transportation (Caltrans) has identified the potential to provide airports, particularly rural airports and helipads, with comprehensive and accurate meteorological data by integrating airport weather systems with those used by other agencies. In this project, the Western Transportation Institute (WTI) has worked in partnership with the Mineta Transportation Institute at San Jose State University to identify the specific data needs of aviation professionals, and to investigate whether data from existing sources can be integrated into a WeatherShare -type system to fulfill those needs. (WeatherShare is a Caltrans sponsored research system developed by the Western Transportation Institute at Montana State University and is focused on weather information for surface transportation.) The AWOS and RWIS project is targeted at small, underserved rural airfields and heliports.During this project, a systems engineering process was followed. Such a system engineering approach increases the likelihood that the system will work, satisfy customer needs, and meet acceptable cost and schedule constraints. Through a literature review and a survey of a representative focus group from rural airports/heliports in Northern California, a high-level user requirements analysis was conducted, a system concept was created and a prototype system was developed. The system aggregates quality-controlled surface weather information, Caltrans closed-circuit television (CCTV), National Weather Service (NWS) radar, satellite imagery, winds aloft readings and several other aviation-related weather data from various sources, into a web-based interface accessible by pilots and operators from different airports through the Internet.

A preliminary cost estimate was developed to show acquisition, maintenance and related costs for Road Weather Information Systems (RWIS), Automated Weather Observation Systems (AWOS), and Automated Surface Observing Systems (ASOS). A cost–benefit analysis was developed to identify, quantify and demonstrate the benefits, costs and institutional issues associated with AWOS/ASOS and RWIS data linkage, as well as the potential for cooperative maintenance and deployment of such systems. An evaluation of the prototype system through an online survey was conducted to investigate the usability and utility of the system, the data provided and corresponding interfaces.

This report summarizes the various activities that occurred during the course of the project, including:

- Task 1: Literature Review and Background
- Task 2: System Concept
- Task 3: Requirements Analysis
- Task 4: Laboratory Prototype
- Task 5: Controlled Field Demonstration Prototype
- Task 6: Evaluation
- Task 7: Cost–Benefit Analysis

. Some recommendations are presented based on the findings of the cost–benefit analysis and the evaluation of the demonstration prototype.

At the conclusion of this effort, all project deliverables will have been delivered, and the project will have achieved its goals.

# 1. INTRODUCTION

The purpose of this document is to summarize the work completed during the Integration of AWOS with RWIS project.

## 1.1. Project Goals

The goal of the Integration of AWOS with RWIS project was to provide airport managers, air traffic controllers, pilots, and operators of air ambulance services with comprehensive and accurate meteorological data by integrating weather systems they currently use with systems used by other agencies. Implementing such an integrated system is expected to improve safety and increase efficiency in their operations.

In particular, data from aviation Automated Weather Observing Systems (AWOS), Automated Surface Observing Systems (ASOS) and surface transportation Roadside Weather Information Systems (RWIS) could be integrated to provide wider area of coverage for multiple agencies. Treating these (currently) independent systems as a larger, integrated system could achieve greater levels of efficiency and lead to cost savings through coordination of operations and maintenance as well as planning for future deployment of these systems.

## 1.2. Project Tasks

The work plan for the Integration of AWOS with RWIS project consisted of the following eight tasks:

- Task 1: Literature Review and Background
- Task 2: System Concept
- Task 3: Requirements Analysis
- Task 4: Laboratory Prototype
- Task 5: Controlled Field Demonstration Prototype
- Task 6: Evaluation
- Task 7: Cost–Benefit Analysis
- Task 8: Recommendations

This report provides descriptions of each task and detailed summaries of the results.

# 2. LITERATURE REVIEW AND BACKGROUND

Prior to developing the integrated system, the research team conducted a literature review of existing similar integration projects, particularly those addressing aviation needs. The team also studied other sources of aviation and surface weather information to determine the current trends in weather systems, tools, reports, data, resources, lessons learned and technologies used.

The literature review looked at 41 websites/applications that were identified as potential information sources. They were categorized into three main areas: aviation, surface, and aviation and surface. Some important findings are summarized below.

- While there is a significant amount of weather data available, it is difficult to find a source that provides comprehensive, all-encompassing weather information.
- Meteorological Aviation Report (METAR), Terminal Aerodrome Forecasts (TAF), Airman's Meteorological Advisory (AIRMET), ), Significant Meteorological Advisories (SIGMET), Pilot Reports (PIREPS) and Notice to Airmen (NOTAM) reports emerged as the most informative weather reporting products provided by the aviation web resources. The most commonly accessed aviation weather reporting product among the aviation weather resources is Radar, followed by METAR.
- These weather products (METAR, TAF, AIRMET, SIGMET, NOTAM, and PIREP) provide information in raw data formats. This has implications for the design of other weather products that might use their data to express complex weather information in ways simple enough to be useful to surface transportation and aviation personnel.
- Most of the websites generate weather reports based the National Weather Service (NWS) data.
- A flight path tool is available at the NWS website that helps users to view weather data along the route of a flight.
- Weather remains a major cause of general aviation fatalities. While weather was cited as causal in only 4 percent of general aviation (GA) accidents, it accounted for 12 to 17 percent of fatalities. That’s because about 70 percent of weather-related accidents prove fatal (AOPA, 2005).
- A preliminary analysis on costs and benefits of AWOS/ASOS and RWIS systems found that installation and maintenance costs for the systems are high.

From these findings, the project team concluded that there could be benefit in having a central weather repository that provides comprehensive weather reports with high accuracy and lower cost relative to deployment of large numbers of additional AWOS/RWIS.

The project team also worked with Caltrans to collect information on locations and functionality of AWOS/ASOS and RWIS stations in the region, and locations of air fields, heliports and other relevant facilities. This information was compared to the location and functionality of weather stations in the region, including those used in the WeatherShare system. Locations, frequency of reporting, sensor types, reporting details, etc., were used to characterize current coverage. An Initial Station and Airfield/Heliport Site Analysis was conducted to characterize the distribution of the aviation AWOS/ASOS stations in California as well as RWIS and other stations in the WeatherShare system with respect to airfields and heliport sites. The results showed that the current WeatherShare system could better meet user needs by further integrating AWOS and ASOS data. The detailed literature review and Initial Station and Airfield/Heliport Site Analysis Summary are provided in separate documents: Integration of Aviation Automated Weather Observation Systems (AWOS) with Roadside Weather Information Systems (RWIS) – Literature Review; and Integration of Aviation Automated Weather Observation Systems (AWOS) with Roadside Weather Information Systems (RWIS) – Preliminary, High-Level Requirements Analysis and System Concept.

# 3. SYSTEM CONCEPT

The project team developed a system concept document corresponding to the Systems Engineering "Vee" model (Figure 1) to serve as an early "paper prototype" for the data integration system that could be used as a "straw man" for subsequent discussion and development.

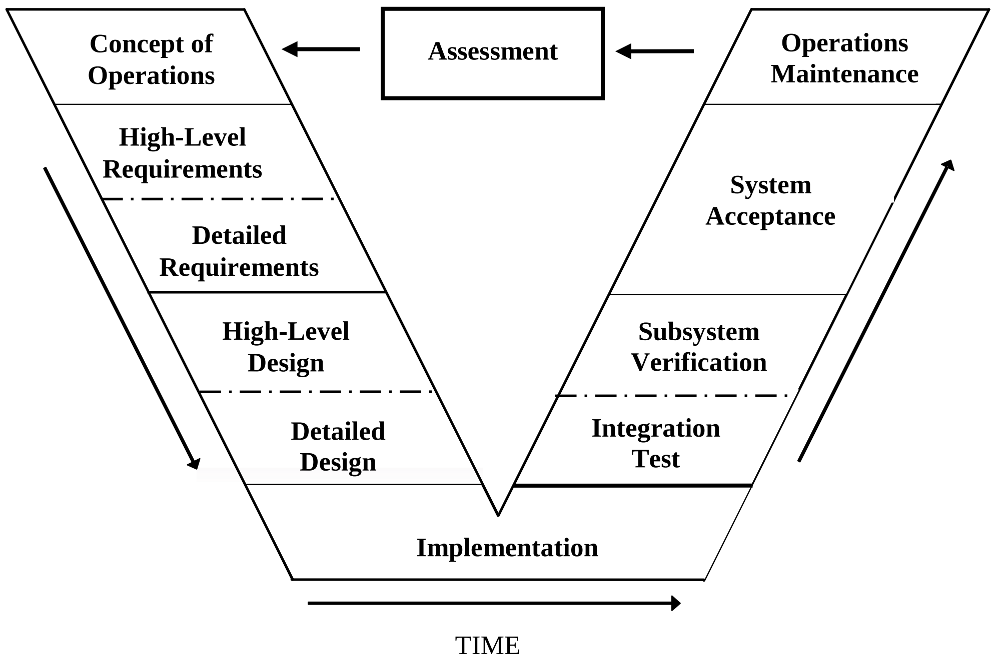


**Figure 1: V Model**

Current practices were identified and a statement of need was created. A web-based application using a Google Maps user interface with multiple aviation data layers was proposed to meet identified needs. The system shall provide reliable access to quality-controlled surface weather information, Caltrans CCTV, radar, satellite images, winds aloft data, and several other aviation-related weather data feeds from various sources. All of this information would be integrated into the system with one user-friendly interface. The end user would enable or disable any of the layers and save the selections as a profile in a URL. Figure 2 shows the data flow of such a system.

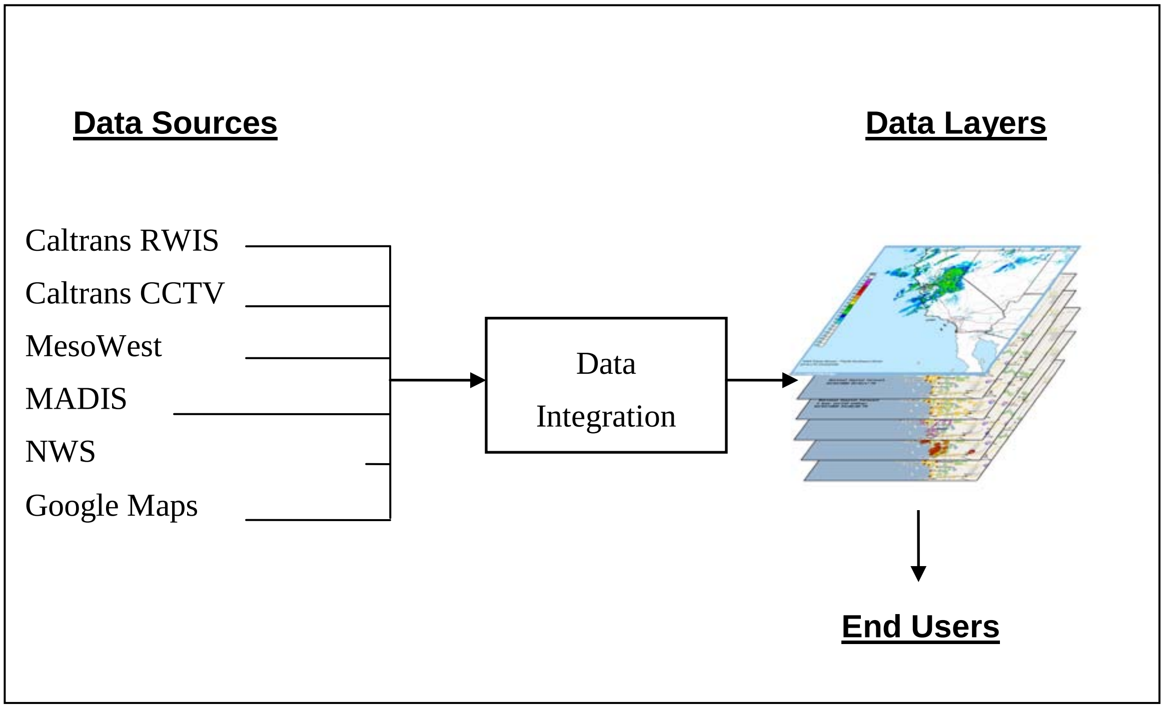


**Figure 2: Data Flow of System.**

Detailed information about the system concept is provided in a separate document: Integration of Aviation Automated Weather Observation Systems (AWOS) with Roadside Weather Information Systems (RWIS) – Preliminary, High-Level Requirements Analysis and System Concept.

# 4. REQUIREMENTS ANALYSIS

The project team conducted the preliminary, high-level requirements analysis based on the focus group survey summary as well as the literature review document. The survey results indicated that the weather-related needs of small airports are not currently being served in a way that is reliable and easy to understand. A system that is easy to access, read and understand, and that contains data from a variety of sources, could help to meet their needs. The literature review also helped to identify many valuable functional requirements that could be incorporated into the system.

The System Engineering Guidebook for ITS was followed throughout the process of defining user requirements. The Guidebook defines seven categories of requirements: functional, performance, interface, data, non-functional, enabling, and constraints. These requirements together define what the system is supposed to do, how well the system should function, and includes operational conditions and constraints. Not all of these applied to the development of this system concept. The project team identified and documented the functional, data, interface, performance, and non-functional requirements that were necessary for development of the system concept of this project.

The detailed preliminary, high-level requirements summary is provided in a separate document: Integration of Aviation Automated Weather Observation Systems (AWOS) with Roadside Weather Information Systems (RWIS) – Preliminary, High-Level Requirements Analysis and System Concept.

# 5. LABORATORY PROTOTYPE

This section describes the prototype system. Section 5.1 provides an overview of the system architecture. Section 5.2 details the data sources and update frequency. Section 5.3 details the server hardware and software configuration, and Section 5.4 describes the user interface for individual layers. Note that for all practical purposes, the laboratory prototype is identical to the controlled field demonstration prototype.

## 5.1. System Architecture

The laboratory prototype system is a web-based application using a Google Maps user interface with multiple aviation-related data layers. The system retrieves surface weather information, Caltrans CCTV, radar, satellite, winds aloft, and several other types of aviation-related weather data from various sources. The data is gathered in text or raster image format and then stored on a server. All of this information is integrated into the system with one user-friendly interface. Pilots or operators from different airports can access the system and view the weather information through the Internet.

A three-tiered architecture was adopted, including presentation, data and application logic tiers. The overall architecture used for this prototype system is shown in Figure 3. The data presentation tier is the topmost level of the application. It serves as a user interface between HTML clients and a database or file system, and presents the end user with all the requested information. The data storage tier consists of a database server and a file system to store and provide all the surface and aviation weather data, weather station meta data (name, latitude, longitude, elevation, data source, etc.), raster layers (PNGs, JPEGs, etc.), and XML raw data. The application logic tier provides the data parsing, quality control, raster generation, and application functionalities.

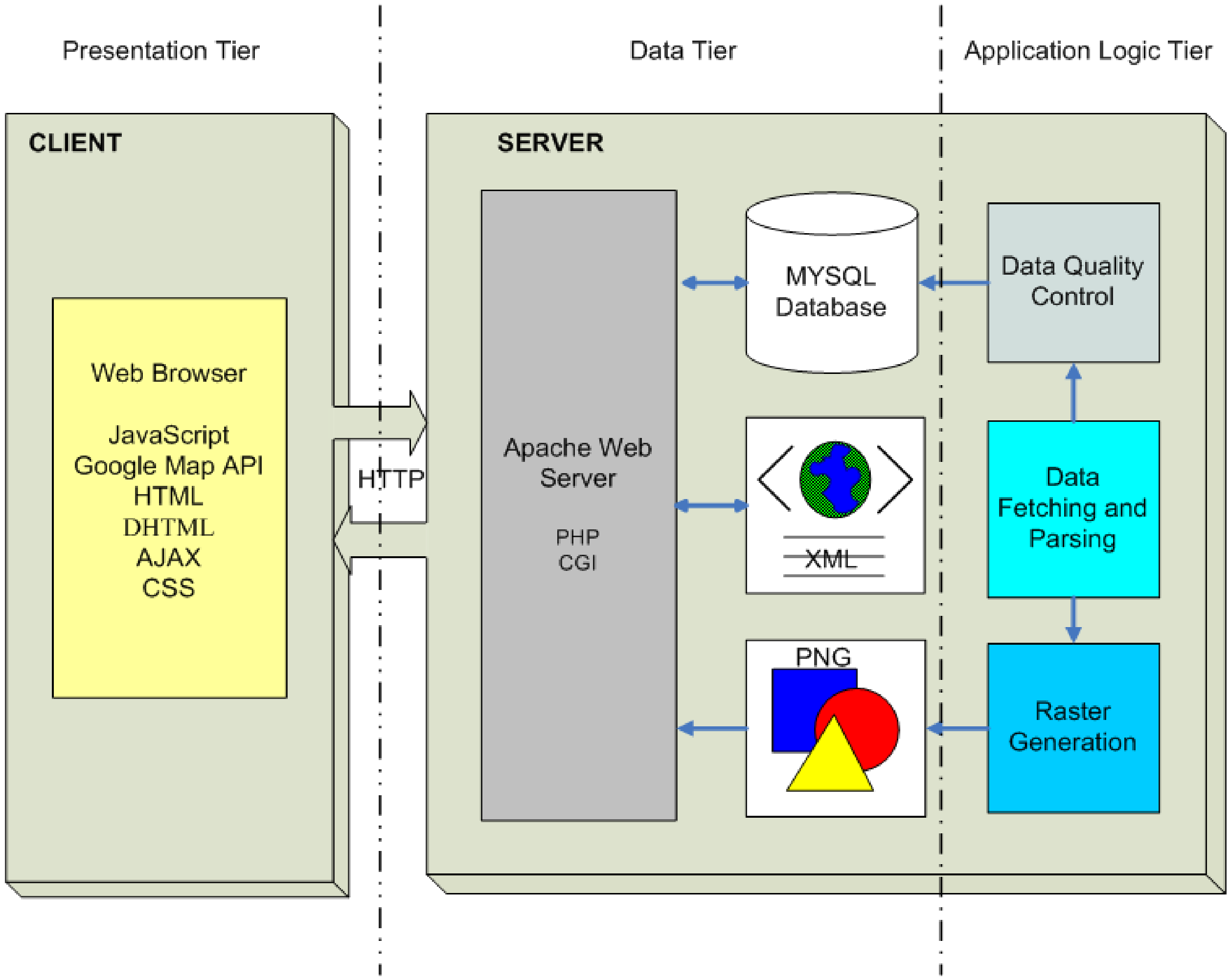


**Figure 3: A Three-tiered Architecture.**

## 5.2. Data Sources and Update Frequency

The system provides a single source for the following weather information:

- Surface weather data layers via WeatherShare, which acquires weather data from MesoWest at the University of Utah and MADIS at the National Weather Service, along with RWIS readings from Caltrans
- NWS Radar Mosaic—Pacific Southwest Sector
- National Digital Forecast Database layers from the NWS via WeatherShare
- NWS Watches, Warnings, and Advisories layer via WeatherShare
- NWS wind/temperature aloft
- (Pilot Reports) PIREPS
- METAR Reports Layer
- Terminal Aerodrome Forecasts (TAF) data layer
- Flight Path Profile
- Caltrans CCTV

The weather information is displayed as separate data layers and presented in the presentation tier. See the following descriptions for details about the different data sources and their update frequency.

### 5.2.1. Surface Layers

The system provides surface layers, including MADIS, MesoWest, Caltrans RWIS, and Caltrans CCTV. Note that there is some overlap in the stations provided by MADIS and MesoWest. The number of stations, their update frequency and the sensor readings are as follows:

- MADIS (690 stations): every 15 minutes

  *Air Temperature, Relative Humidity, Avg Wind Speed, Avg Wind Direction, Max Wind Gust Speed, Max Wind Gust Dir, Dew-point Temp, Atmospheric Pressure, Fuel Moisture, Fuel Temperature, Precipitation Rate, Precipitation in 24 Hours*

- MesoWest (2,474 stations): every 15 minutes

  *Air Temperature, Relative Humidity, Avg Wind Speed, Avg Wind Direction, Max Wind Gust Speed, Atmospheric Pressure, Solar Radiation*

- Caltrans RWIS (107 stations): every 15 minutes

  *Air Temperature, Dew-point Temp, Max Temp, Min Temp, Avg Wind Speed, Max Wind Gust Speed, Avg Wind Direction, Max Wind Gust Dir, Relative Humidity, Precipitation Intensity, Precipitation Rate, Cumulative Precipitation, Visibility*

- NWS Observed 24-hour precipitation (raster covers all of California): Twice in 24 hrs

- Caltrans CCTV (26 sites): every 15 minutes
- NDFD Forecast data: every 60 minutes

  *Air Temperature, Humidity, Avg Wind Speed, Avg Wind Direction, Max Wind Gust Speed, Max Wind Gust Dir, Sky Cover, 12-hour Probability of Precipitation, 6-hour Amount of Precipitation, Snow, weathercondition*

- NWS Warnings, Watches and Advisories: every 15 minutes

  **Warnings:** *Tornado, Flash flood, Blizzard, Winter Storm, High Wind, Storm, Avalanche, Severe Weather Statement, Flood, Red flag, Heavy Freezing Spray*

  **Watches:** *Flash Flood, Winter Storm, Flood, High Wind, Fire Weather, Coastal Flood Statement, Special Weather Statement, Short-term Forecast*

  **Advisories:** *Winter Weather, Flood, High Surf, Small Craft, Brisk Wind, Lake Wind, Wind*

### 5.2.2. Aviation Layers

The system also provides the aviation layers data, including METAR, PIREPS, TAF, and Radar and Satellite images. The number of stations, their update frequency and the data collected by each data provider are as follows:

- METAR (91 stations): every 60 minutes

  *Air Temperature, Relative Humidity, Wind Speed and direction, Visibility, Sky Condition, Dew-point Temp, Atmospheric Pressure*
- PIREPS: every 15 minutes

  *Air Temperature, Relative Humidity, Avg Wind Speed,Avg Wind Direction,Max Wind Gust Speed, Atmospheric Pressure, Solar Radiation*

- TAF (107 stations): every 15 minutes

  *Air Temperature, Dew-point Temp, Max Temp, Min Temp, Avg Wind Speed, Max Wind Gust Speed, Avg Wind Direction, Max Wind Gust Dir, Relative Humidity, Precipitation Intensity, Precipitation Rate, Cumulative Precipitation, Visibility*
- Radar: every 15 minutes
- Satellite: every 15 minutes

## 5.3. Server Configuration

The prototype system is running on a LAMP (Linux, Apache, MySql, PHP) server with the following software and hardware components:

Software:

- Debian Linux 5.0
- Linux Kernel 2.6.26-1-amd64
- MySQL 5.0.51a
- PHP 5.2.6-1

- PERL 5.8.8
- Apache 2.2.9

Hardware:

- Dell PowerEdge 2950 2U rack-mount server
- Two Quad-Core Intel® Xeon™ 3.0 GHz X5450 CPUs
- Two 300GB hard drives in a RAID 1 array
- 16 GB memory

## 5.4. Overview of User Interface

The prototype system has been deployed as a web-based application to work within Internet Explorer or Firefox browsers. The Google Maps API, HTML, DHTML, JavaScript, AJAX, PHP, XML, and Web 2.0 were used in developing the user interface. This solution allows more robust mapping with map, satellite, terrain, or hybrid views of the mapped area. The Google Maps API facilitates the use of controls for panning and zooming into a desired section of the map. Many users are already familiar with the Google Maps interface. Figure 4 shows the home page of the prototype system. By default, it will show the current surface conditions by sensor type —in this case, air temperature.

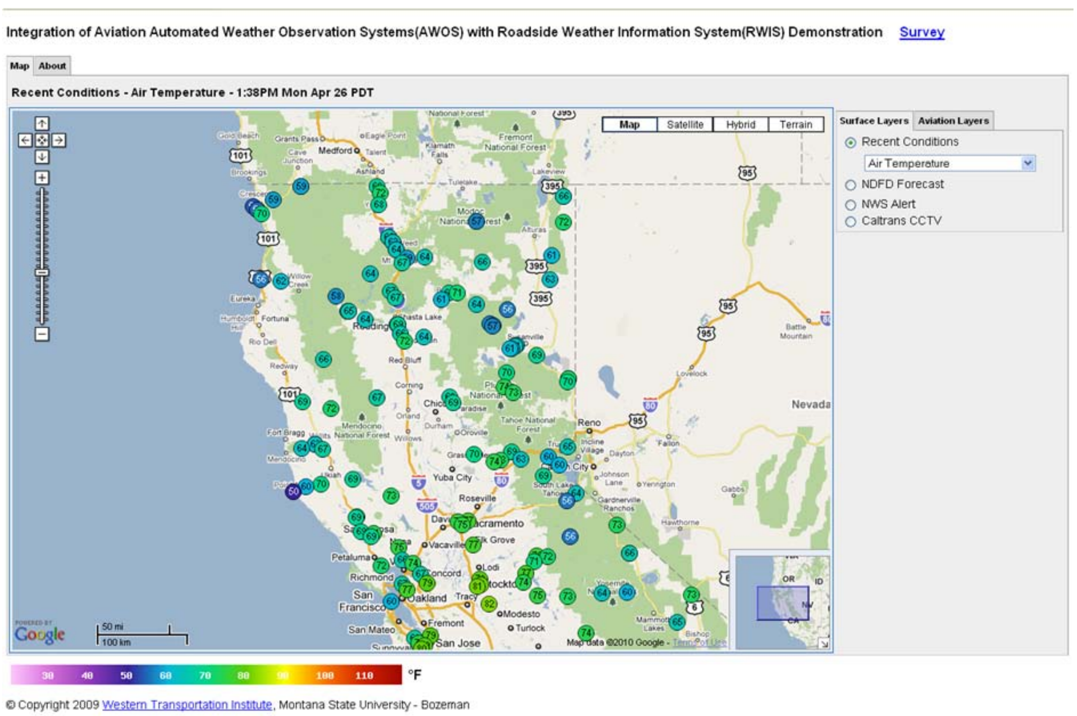


**Figure 4: Aviation AWOS with RWIS Prototype Home Page**

The Google Maps panel contains layer display and zoom controls. A tab panel control on the right side of the interface allows users to navigate between the Surface Layers tab and the Aviation Layers tab, and also allows users to toggle different layers within the tab display by checking different radio buttons. The Surface Layers tab display includes Recent Conditions, NDFD Forecast, NWS Alert and Caltrans CCTV layers. The Aviation Layers tab display includes AWOS/ASOS (METAR), Pilot Reports (PIREPS), Terminal Aerodrome Forecasts (TAF), NWS CONUS Merged Reflectivity Composite Radar, Satellite data, Wind Aloft, and Temperature Aloft layers. Some screen shots of different layers are presented in the following section.

The system integrates all real-time surface weather station data from the WeatherShare system into the Recent Conditions layers under the Surface layers tab display. See Figure 5 and Figure 6 for example displays of recent conditions for wind speed and NWS Observed 24-hour Precipitation. Clicking on a station icon invokes a detail bubble with all the data from that station.

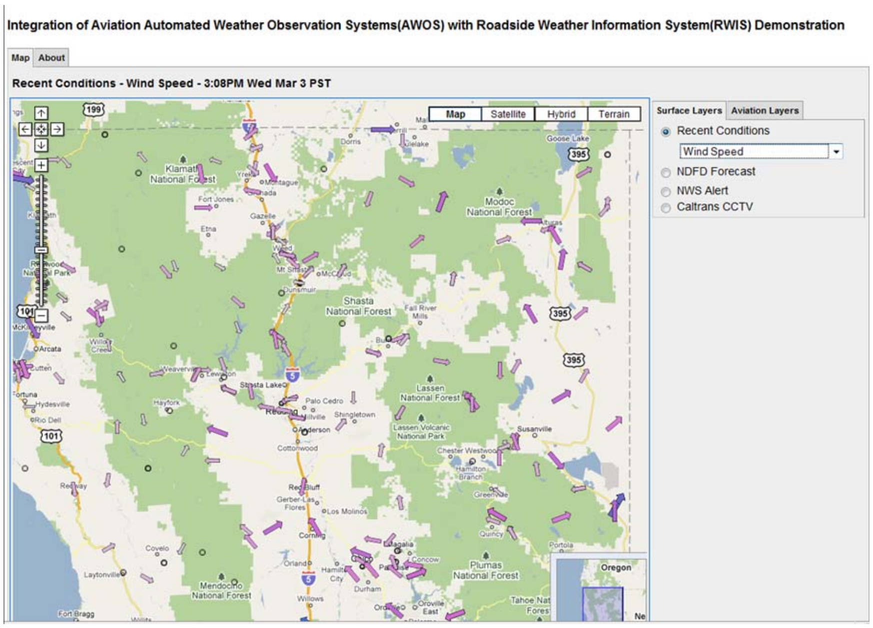


**Figure 5: Surface Layer – Recent Conditions, Wind Speed**

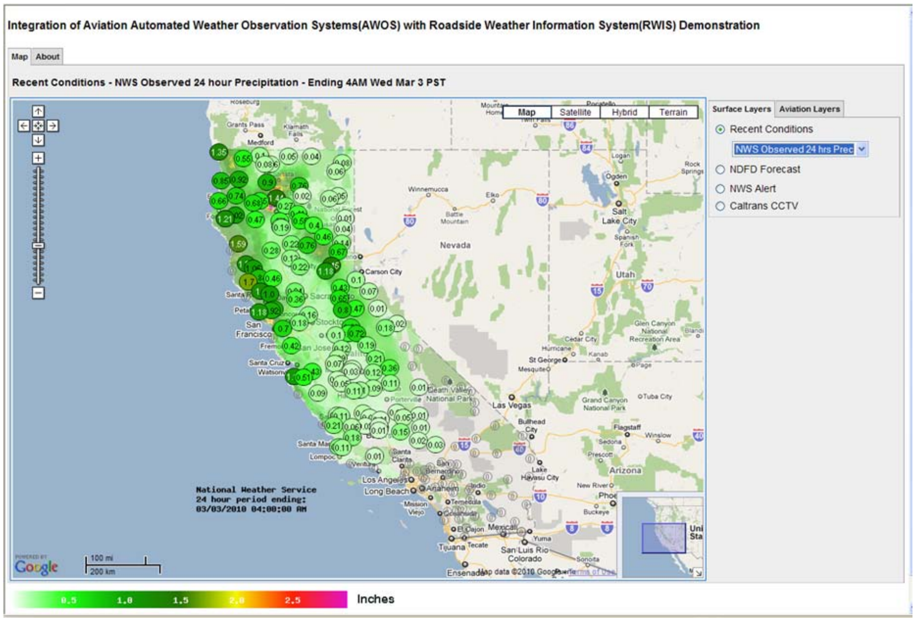


**Figure 6: Surface Layer – Recent Conditions, NWS Observed 24-hr Precipitation**

Figure 7 shows a weather condition forecast from the National Weather Service's National Digital Forecast Database (NDFD) for California. The data is color coded, and different weather icons are used and are clickable for display of detailed information. The interface uses the same legend/colors employed by the National Weather Service to maintain consistency. It's easy to spot areas where rain and snow are predicted. See Figure 8, Figure 9 and Figure 10 for the NDFD Forecast layer displays of air temperature, snow and 6-hour precipitation amounts.

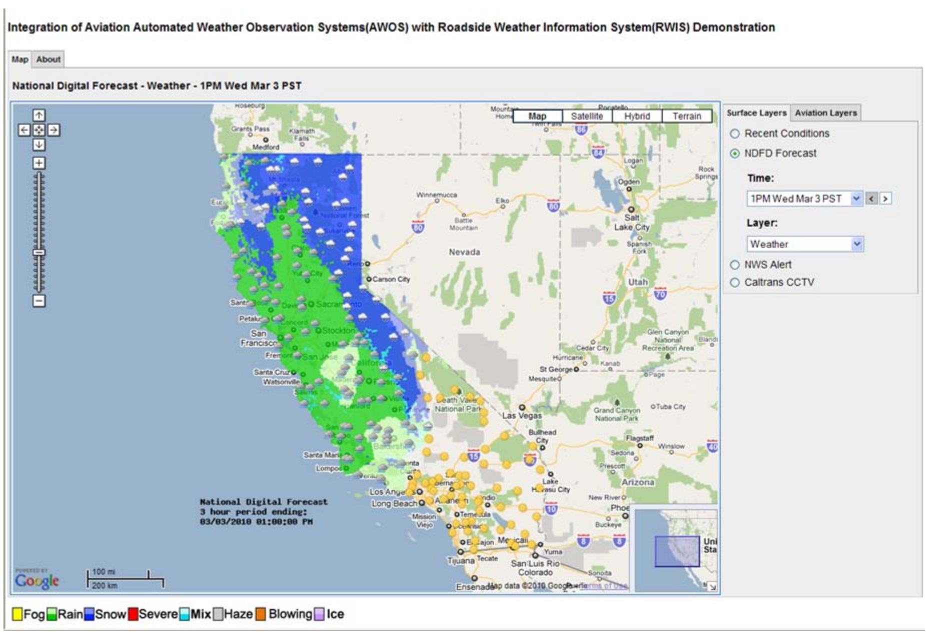


**Figure 7: Surface Layer – Forecast Weather**

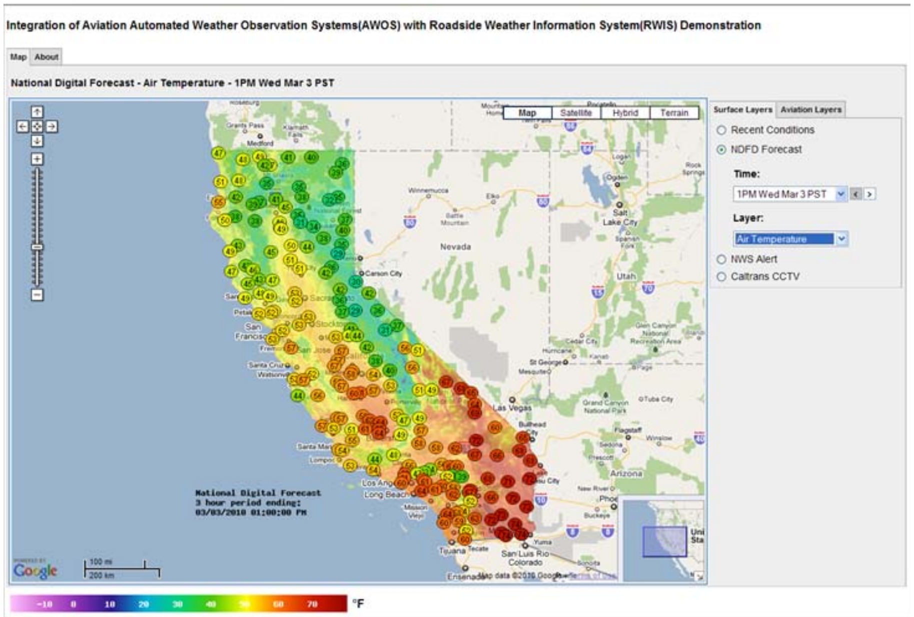


Figure 8: Surface Layer – Forecast Air Temperature

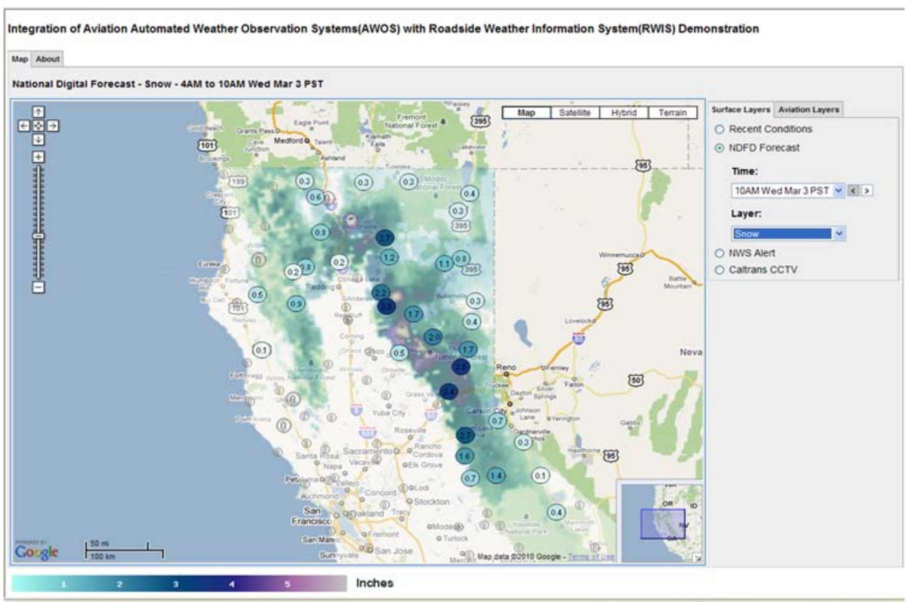


Figure 9: Surface Layer – Forecast Snow

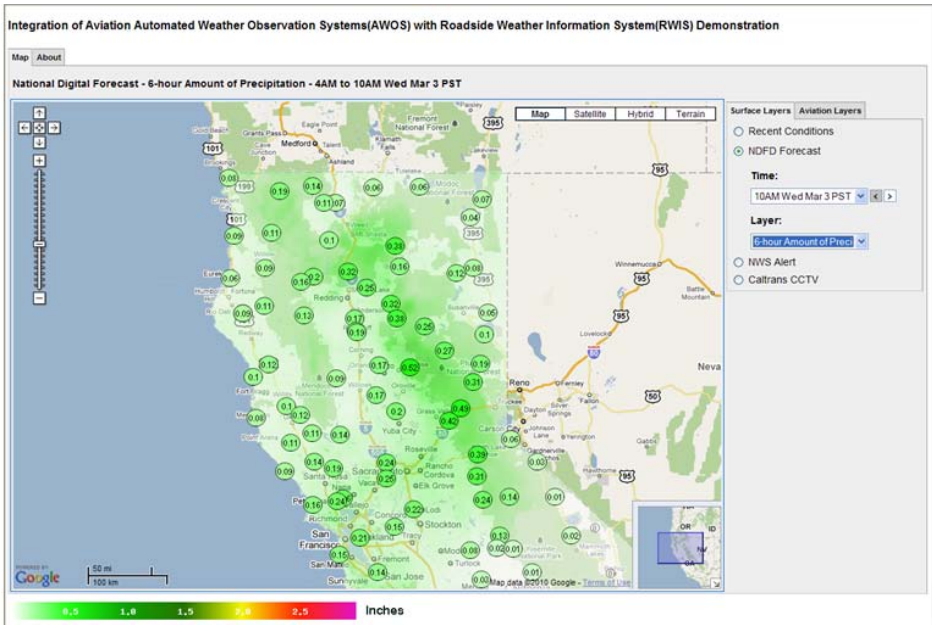


**Figure 10: Surface Layer – Forecast 6-hour Amount of Precipitation**

The Caltrans CCTV image layer is provided to allow users to visually check current real conditions near CCTV sites. Figure 11 shows an example CCTV image.

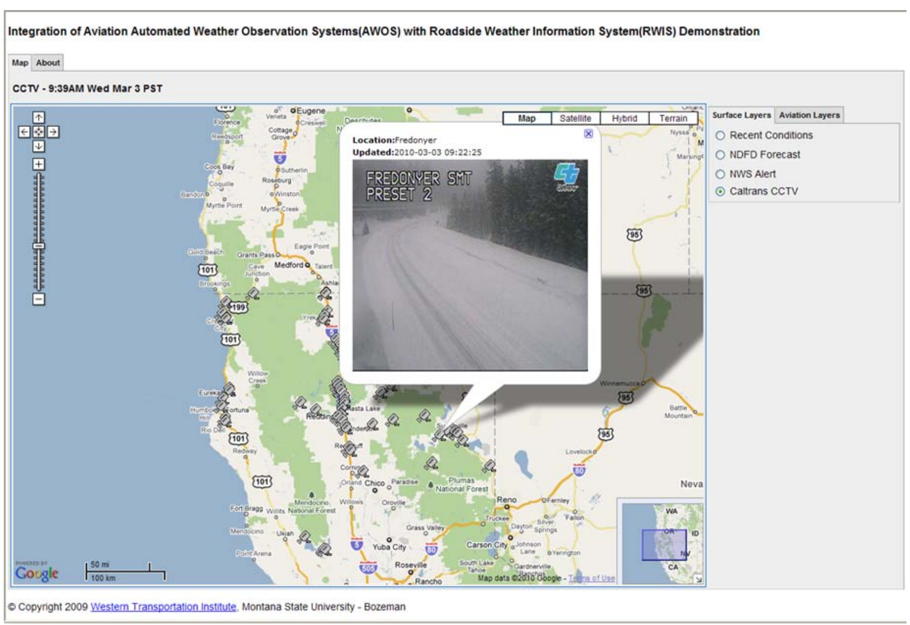


**Figure 11: Surface Layer – Caltrans CCTV**

Figure 12 shows an example NWS Alert display. Clicking on an icon shows detailed NWS Alert information (Figure 13).

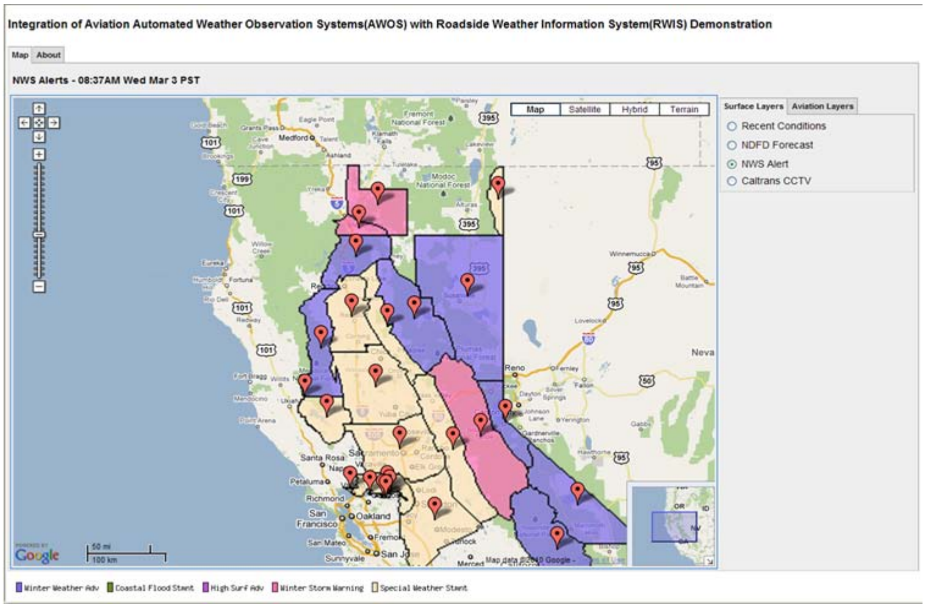


**Figure 12: Surface Layer – NWS Alerts**

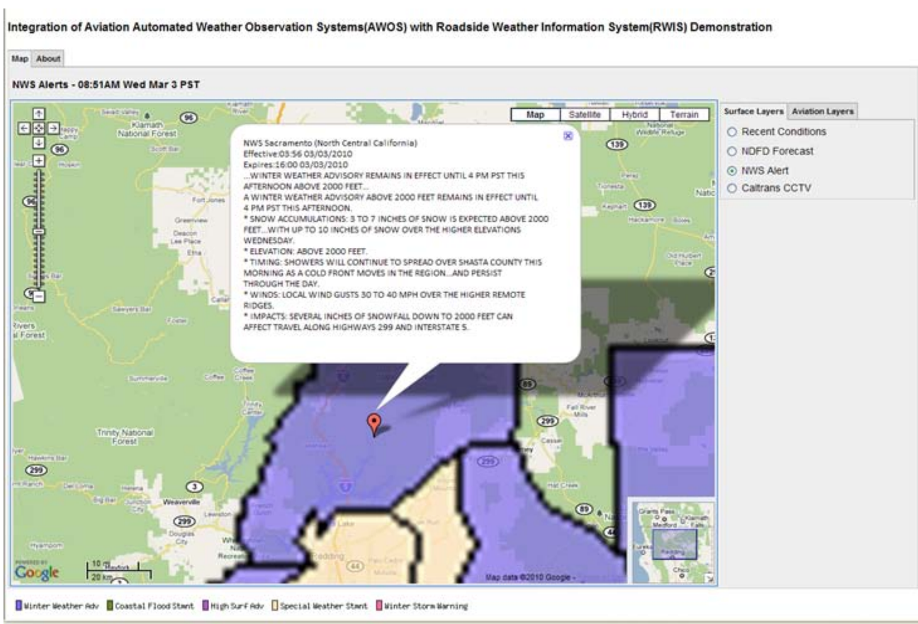


**Figure 13: Surface Layer – NWS Alert Detail**

See Figure 14 for an example of NWS CONUS Merged Reflectivity Composite layer display. Figure 15 is an example of NWS Satellite – IR Temperature layer display. Note here that sometimes the satellite image completely covers the map, so a county outline layer is provided for the satellite layer display to allow users to identify the area. The user can enable or disable this county boundary layer by clicking the “show boundary” checkbox.

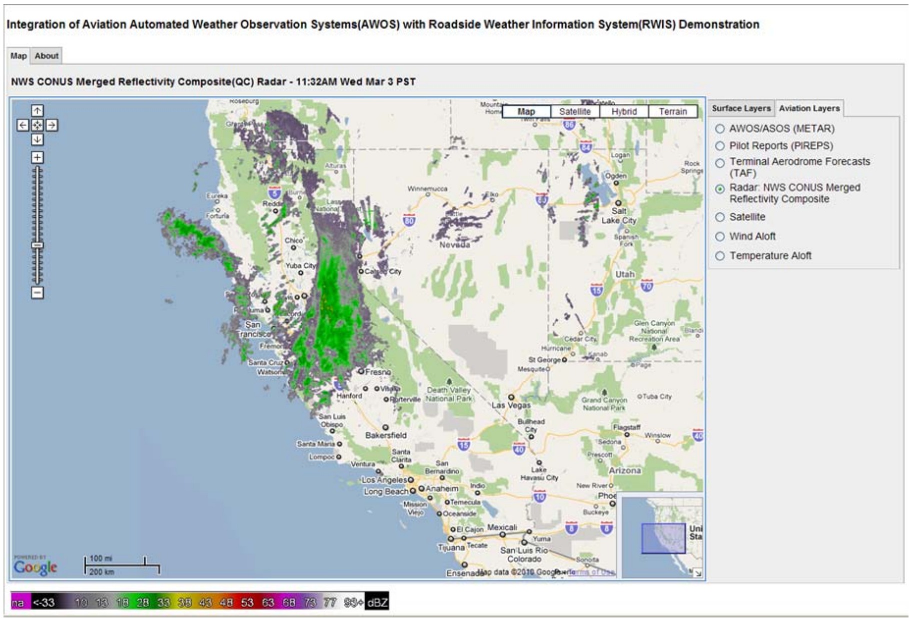


**Figure 14: Aviation Layer – RADAR – NWS CONUS Merged Reflectivity Composite**

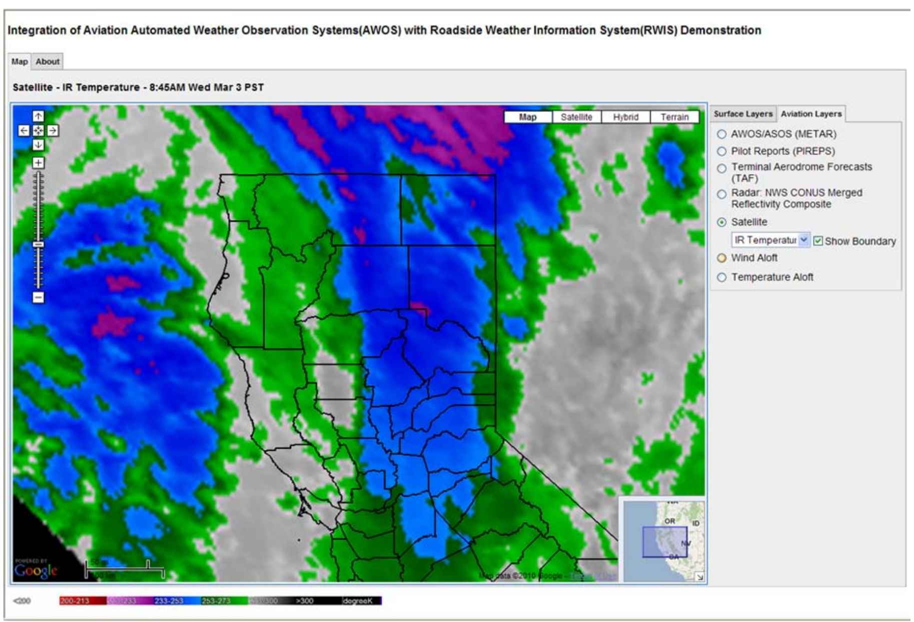


**Figure 15: Aviation Layer – Satellite IR Temperature**

The system also provides AWOS/ASOS (METAR), Pilot Reports (PIREPS) and Terminal Aerodrome Forecast (TAF) layers under the aviation tab. See Figure 16, Figure 17 and Figure 18 for example displays of individual layers. Note that METAR data is provided in both METAR format and an easy-to-read English format. The PIREPS and TAF data are only presented in encoded form in this prototype. Conversion to easy-to-read English format for this data is desirable, but was not accomplished within this project.

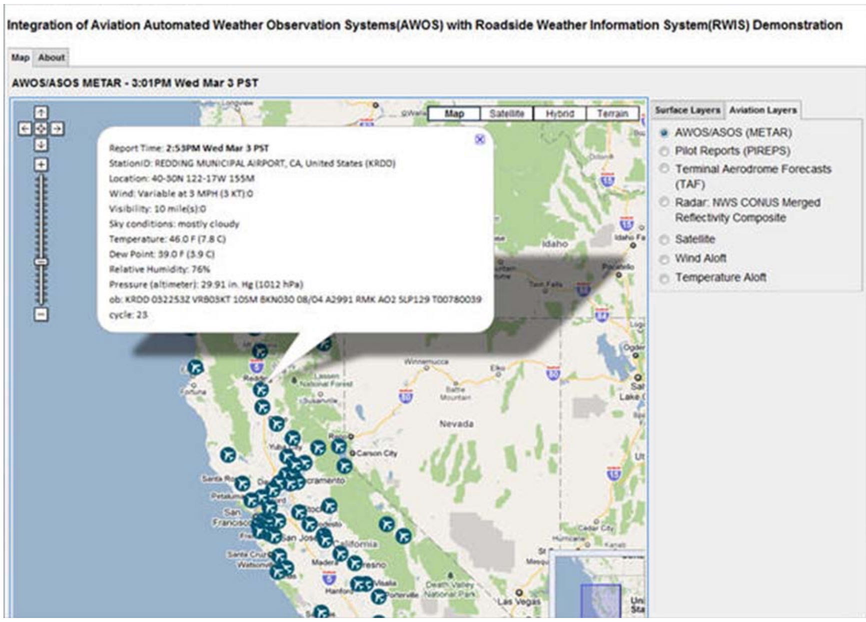


**Figure 16: Aviation Layer – AWOS/ASOS (METAR)**

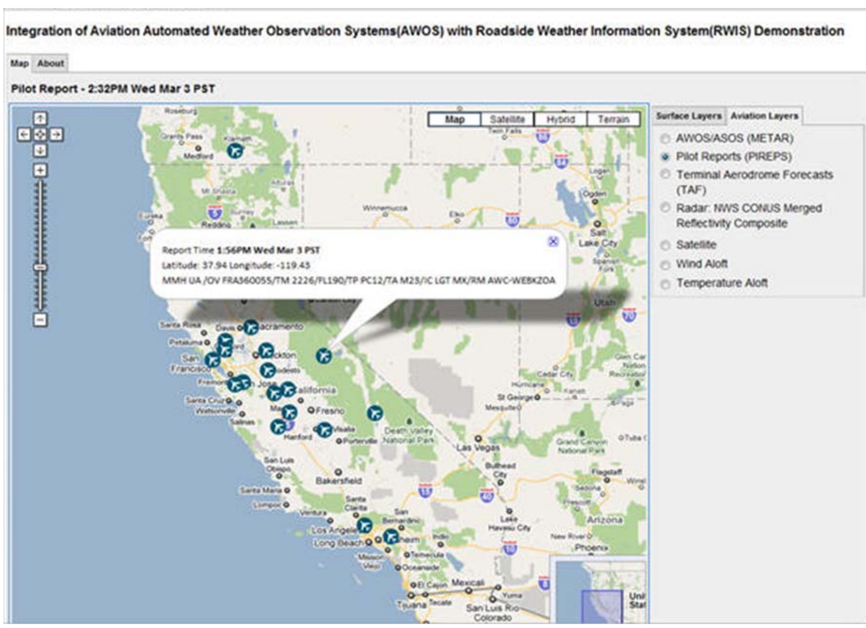


**Figure 17: Aviation Layer – Pilot Reports (PIREPS)**

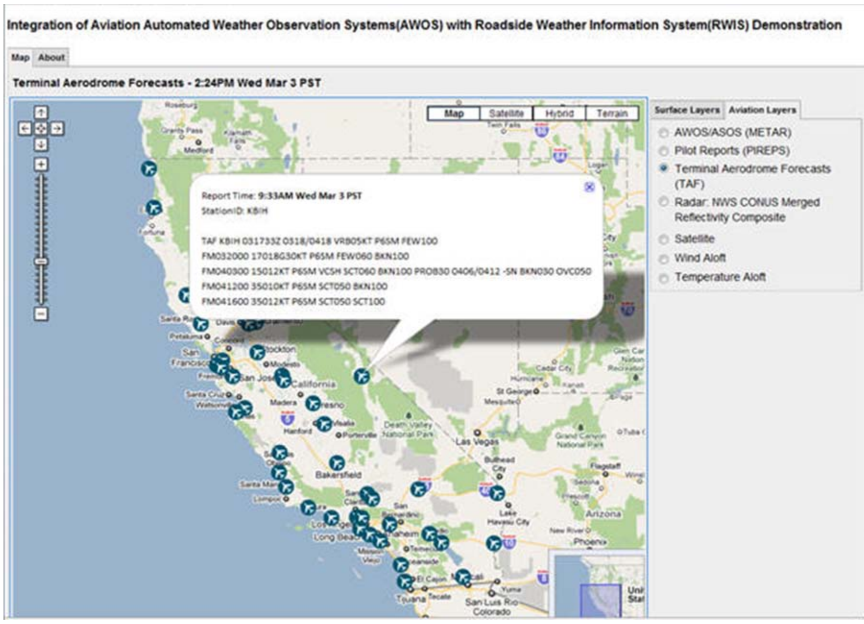


**Figure 18: Aviation Layer – Terminal Aerodrome Forecasts (TAF)**

The system provides one-hour forecast wind/temperature aloft data from the National Centers for Environmental Prediction (NCEP). Note that the forecast wind/temperature data is available for up to 84 hours from NCEP. We currently only provide one-hour forecast data in this prototype for demonstration and evaluation purposes. The timeframe may be expanded in a subsequent phase. See Figure 19 and Figure 20 and for examples.

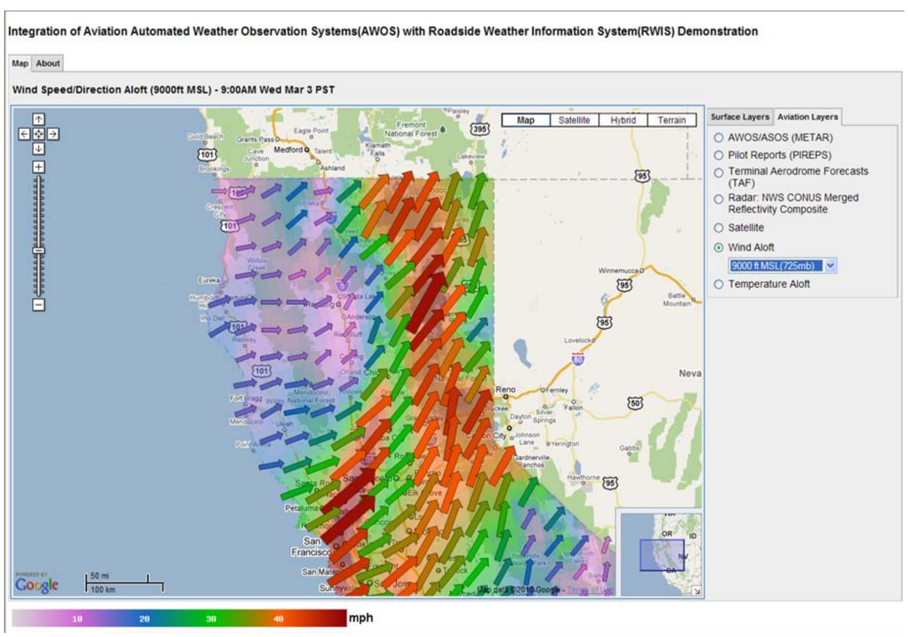


**Figure 19: Aviation Layer – Wind Aloft**

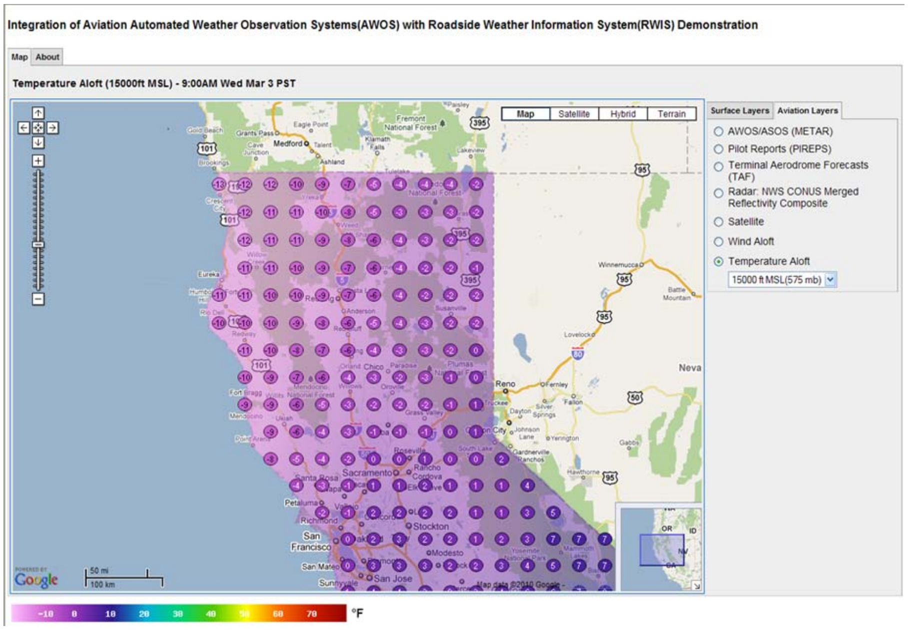


**Figure 20: Aviation Layer – Temperature Aloft**

# 6. CONTROLLED FIELD DEMONSTRATION PROTOTYPE

The prototype system described in Chapter 5 provided necessary functionality and was considered to be suitable for the controlled field demonstration and evaluation. Formal evaluation has been conducted and summarized in the following chapter to determine usefulness of the system and viability for prospective production.

# 7. EVALUATION

This section provides findings from a survey that was administered during the spring of 2010. The questions in the survey covered the following:

- The frequency of use of the prototype system.
- When and for how long the prototype system is used.
- How useful is the data offered in the prototype.
- How useful are the prototype's features.
- Opinions on the prototype system's organization and ease of use.
- Additional information that could be incorporated into the system .
- The chief benefits of using the system from the viewpoint of their current position.
- Further comments on how the system can be improved.

See the Appendix for a complete list of survey questions.

There were a total of 16 respondents to the survey questions, although not all respondents answered every question. The results of the survey are presented in the following section.

## 7.1. Survey Responses

### 7.1.1. Contact Information – Organization

A small, but relatively diverse group responded to the survey. The largest single group represented was Caltrans, although the majority of responses were from organizations other than Caltrans.

**Table 1: Organizations Responding to Survey**

| Organization | Count |
|---:|---:|
| Caltrans-Division of Aeronautics | 2 |
| Caltrans, District 2 | 1 |
| Caltrans | 2 |
| AirCarriage, LLC | 1 |
| EAA Chapter 427   Chico, CA | 1 |
| PACE Engineering | 1 |
| County of Siskiyou | 1 |
| EAA/AOPA | 1 |
| Emergency Medical Services Authority | 1 |
| No Organization Indicated | 4 |
| *No. of Respondents who Answered the Question* | 15 |

### 7.1.2. Frequency of Visits to AWOS with RWIS System Site

No users are currently using the website all the time or on an hourly basis. This response is consistent with this being a prototype that was introduced only months ago.

**Table 2: Frequency of Visits to AWOS with RWIS System Site**

| Response | Percent | Count |
|---|---|---|
| Website is open all the time | 0.0% | 0 |
| Hourly | 0.0% | 0 |
| Daily | 18.8% | 3 |
| Weekly | 31.3% | 5 |
| Monthly | 6.3% | 1 |
| Not at all | 25.0% | 4 |
| Other (please specify) | 18.8% | 3 |
| *No. of Respondents who Answered the Question* | | 16 |

Other Responses:

- I just saw it for the first time
- When I have a need to travel or just update my awareness
- Twice monthly w/o RWIS

### 7.1.3. When Information is Used

Information from the system is primarily used during daytime hours and under changing conditions.

**Table 3: When Information is Used**

| Response | Percent | Count |
|---|---|---|
| Daytime hours | 61.5% | 8 |
| Nighttime hours | 15.4% | 2 |
| Under changing conditions | 53.8% | 7 |
| During incident conditions (storm/fire, etc.) | 23.1% | 3 |
| When Supervisor on-duty | 7.7% | 1 |
| When Supervisor off-duty | 0.0% | 0 |
| Other (please specify) | 23.1% | 3 |
| *No. of Respondents who Answered the Question* | | 13 |

Other Responses:

- I just saw it for the first time
- Assessing the go/no go decision
- Before a flight or driving

### 7.1.4. Usefulness and Awareness of Information – Surface Layer: Current Conditions

Wind was selected as by far the most useful surface condition layer by survey participants. All surface condition layers were selected as somewhat useful or very useful except for pavement conditions from RWIS. For each surface layer, at least one participant indicated they were unaware of it.

**Table 4: Usefulness and Awareness of Information – Surface Layer: Current Conditions**

| Answer Options | Very Useful | Somewhat Useful | Not Very Useful | Aware of it | Not Aware of it | Response Count |
|---|---|---|---|---|---|---|
| a. Station Locations | 5 | 4 | 0 | 0 | 1 | 10 |
| b. Air Temperature | 5 | 4 | 0 | 0 | 1 | 10 |
| c. Wind Direction and Speed | 8 | 0 | 0 | 0 | 2 | 10 |
| d. Relative Humidity | 2 | 6 | 0 | 0 | 2 | 10 |
| e. Precipitation Last Hour | 2 | 6 | 0 | 0 | 2 | 10 |
| f. Precipitation Last 24 Hours | 3 | 5 | 0 | 0 | 2 | 10 |
| g. NWS Observed 24-Hour Precip | 3 | 5 | 0 | 0 | 2 | 10 |
| h. RWIS Specific Information such as Pavement Conditions | 4 | 3 | 1 | 0 | 2 | 10 |
| i. Station Detail Bubble Information | 4 | 5 | 0 | 0 | 1 | 10 |
| *No. of Respondents who Answered the Question* | | | | | | 10 |

### 7.1.5. Usefulness and Awareness of Information – Surface Layer: Forecast Data

Wind forecasts were also identified as very useful, along with probability of precipitation. Relative humidity and amount of precipitation rated lowest in usefulness.

**Table 5: Usefulness and Awareness of Information – Surface Layer: Forecast Data**

| Answer Options | Very Useful | Somewhat Useful | Not Very Useful | Aware of it | Not Aware of it | Response Count |
|---|---|---|---|---|---|---|
| a. Air Temperature | 5 | 2 | 0 | 0 | 2 | 9 |
| b. Wind Direction and Speed | 8 | 0 | 0 | 0 | 2 | 10 |
| c. Wind Gust Speed and Direction | 8 | 0 | 0 | 0 | 2 | 10 |
| d. Relative Humidity | 2 | 6 | 0 | 0 | 2 | 10 |
| e. Sky Cover | 6 | 2 | 0 | 0 | 2 | 10 |
| f. 12-hour Probability of Precipitation | 8 | 0 | 0 | 0 | 2 | 10 |
| g. 6-hour Amount of Precipitation | 4 | 3 | 0 | 0 | 2 | 9 |
| h. Snow | 6 | 2 | 0 | 0 | 2 | 10 |
| i. Weather | 7 | 1 | 0 | 0 | 2 | 10 |
| j. Data Provided at 3-hour Intervals for Next 24 Hours | 7 | 0 | 0 | 0 | 2 | 9 |
| *No. of Respondents who Answered the Question* | | | | | | 10 |

### 7.1.6. Usefulness and Awareness of Information – Surface Layer: National Weather Service Alerts

Color coding and bubble detail were generally considered useful.

**Table 6: Usefulness and Awareness of Information – Surface Layer: National Weather Service Alerts**

| Answer Options | Very Useful | Somewhat Useful | Not Very Useful | Aware of it | Not Aware of it | Response Count |
|---|---|---|---|---|---|---|
| a. Color-coded and Graphic Display of NWS Alert | 6 | 1 | 0 | 0 | 3 | 10 |
| b. Alert Detail Bubble Information | 6 | 1 | 0 | 0 | 3 | 10 |
| *No. of Respondents who Answered the Question* | | | | | | 10 |

### 7.1.7. Usefulness and Awareness of Information – Surface Layer: Caltrans CCTV Images

CCTV images were also considered useful.

**Table 7: Usefulness and Awareness of Information – Surface Layer: Caltrans CCTV Images**

| Answer Options | Very Useful | Somewhat Useful | Not Very Useful | Aware of it | Not Aware of it | Response Count |
|---|---|---|---|---|---|---|
| a. CCTV images | 6 | 2 | 0 | 1 | 1 | 10 |
| *No. of Respondents who Answered the Question* | | | | | | 10 |

### 7.1.8. Usefulness and Awareness of Information – Aviation Layer: Various Layers

Most of the layers covered by this question were considered useful. Not surprisingly, the AWOS/ASOS (METAR) layer was considered most useful. The satellite IR temperature layer ranked the lowest of all, and quite a bit lower than the other satellite layers.

**Table 8: Usefulness and Awareness of Information – Aviation Layer: Various Layers**

| Answer Options | Very Useful | Somewhat Useful | Not Very Useful | Aware of it | Not Aware of it | Response Count |
|---|---|---|---|---|---|---|
| a. AWOS/ASOS (METAR) data | 10 | 1 | 0 | 0 | 0 | 11 |
| b. Encoded Pilot Reports (PIREPS) | 8 | 2 | 0 | 0 | 1 | 11 |
| c. Terminal Aerodrome Forecasts (TAF) | 8 | 2 | 0 | 0 | 1 | 11 |
| d. Radar: NWS CONUS Merged Reflectivity Composite | 8 | 1 | 0 | 0 | 2 | 11 |
| e. Satellite: IR Temperature | 6 | 4 | 0 | 0 | 1 | 11 |
| f. Satellite: Water Vapor | 9 | 2 | 0 | 0 | 0 | 11 |
| g. Satellite: Visible | 9 | 1 | 0 | 0 | 1 | 11 |
| *No. of Respondents who Answered the Question* | | | | | | 11 |

### 7.1.1. Usefulness and Awareness of Information – Aviation Layer: Wind Aloft

The project team was uncertain of the range that the wind aloft layer should cover since data is available for altitudes higher than the 15,000 ft MSL maximum shown in the Table 9. Results here show that 3000 ft MSL, 6000 ft MSL and 9000 ft MSL are most useful. So, it may not be necessary to expand to higher altitudes.

**Table 9: Usefulness and Awareness of Information – Aviation Layer: Wind Aloft**

| Answer Options | Very Useful | Somewhat Useful | Not Very Useful | Aware of it | Not Aware of it | Response Count |
|---|---|---|---|---|---|---|
| a. 3000 ft MSL (900mb) | 10 | 0 | 0 | 0 | 1 | 11 |
| b. 6000 ft MSL (800mb) | 10 | 0 | 0 | 0 | 1 | 11 |
| a. 9000 ft MSL (725mb) | 10 | 0 | 0 | 0 | 1 | 11 |
| d. 12000 ft MSL (650mb) | 5 | 4 | 0 | 0 | 1 | 10 |
| e. 15000 ft MSL (575mb) | 6 | 4 | 0 | 0 | 1 | 11 |
| *No. of Respondents who Answered the Question* | | | | | | 11 |

### 7.1.1. Usefulness and Awareness of Information – Aviation Layer: Temperature Aloft

Results for temperature aloft are similar to those for wind aloft, with the most interest falling between 3000 ft MSL and 9000 ft MSL.

**Table 10: Usefulness and Awareness of Information – Aviation Layer: Temperature Aloft**

| Answer Options | Very Useful | Somewhat Useful | Not Very Useful | Aware of it | Not Aware of it | Response Count |
|---|---|---|---|---|---|---|
| a. 3000 ft MSL (900mb) | 9 | 1 | 0 | 0 | 1 | 11 |
| b. 6000 ft MSL (800mb) | 9 | 1 | 0 | 0 | 1 | 11 |
| a. 9000 ft MSL (725mb) | 9 | 1 | 0 | 0 | 1 | 11 |
| d. 12000 ft MSL (650mb) | 6 | 4 | 0 | 0 | 1 | 11 |
| e. 15000 ft MSL (575mb) | 5 | 5 | 0 | 0 | 1 | 11 |
| *No. of Respondents who Answered the Question* | | | | | | 11 |

### 7.1.1. Usefulness of General Website Features

The general website functionality that received the lowest rankings included access to historical surface data. Other features received moderate to high ratings.

**Table 11: Usefulness of General Website Features**

| Answer Options | Very Useful | Somewhat Useful | Not Very Useful | Aware of it | Not Aware of it | Response Count |
|---|---|---|---|---|---|---|
| a. Google Map display & zoom function | 10 | 0 | 0 | 0 | 2 | 12 |

| | | | | | | |
|---|---|---|---|---|---|---|
| b. Color-coded weather information and graphic representation | 9 | 1 | 0 | 0 | 2 | 12 |
| c. Historical data access for surface weather stations through screen display | 3 | 3 | 2 | 1 | 3 | 12 |
| d. Historical data access for surface weather stations through CSV file export | 2 | 3 | 2 | 0 | 4 | 11 |
| e. Having the NDFD forecast data mapped to highway mileposts at one mile intervals in addition to the background raster | 5 | 2 | 0 | 1 | 4 | 12 |
| f. Different data layers switching using tab display and radio button | 6 | 1 | 0 | 0 | 5 | 12 |
| g. Auto refresh web page every 3 minutes | 5 | 1 | 0 | 0 | 6 | 12 |
| *No. of Respondents who Answered the Question* | | | | | | 12 |

### 7.1.1. Miscellaneous

In this section, several specific, miscellaneous questions were asked. The responses to these are generally self-explanatory. Several of these responses merit further discussion for possible changes in a subsequent version of the system, including extending data coverage in terms of time and altitude.

**Table 12: Miscellaneous**

| Answer Options | Strongly Agree | Somewhat Agree | Neither Agree nor Disagree | Somewhat Disagree | Strongly Disagree | Response Count |
|---|---|---|---|---|---|---|
| a. The site is well organized and user friendly | 8 | 3 | 1 | 0 | 0 | 12 |
| b. I would like to see NDFD forecast information for more than 24 hours | 5 | 5 | 1 | 0 | 1 | 12 |
| c. I would like to see more/different Radar images (please specify in comments section) | 2 | 3 | 6 | 0 | 0 | 11 |
| d. I would like to see more/different Wind/Temperature aloft at higher altitude (please specify in comments section) | 3 | 1 | 5 | 1 | 1 | 11 |
| e. I would like to see Wind/Temperature aloft at time intervals further out than 1 hour (please specify in comments section) | 5 | 1 | 5 | 0 | 0 | 11 |
| *No. of Respondents who Answered the Question* | | | | | | 12 |

### 7.1.1. Desired Additional Weather Information

The responses to this question are generally self-explanatory.

**Table 13: Desired Additional Weather Information**

| 7. What additional weather information would you like to have, which is not available currently at this site? (Please specify the type, format, frequency of updating, accuracy) | |
|---|---|
| Answer Options | Response Count |
| *No. of Respondents who Answered the Question* | 6 |

Responses:

- Winds and temperature aloft forecasts
- Two- to three-hour forecasts are particularly helpful for general aviation pilots since this is the outside edge of their operational envelope.
- I have no additional needs at this time
- Little more information in bubble.
- Density altitude report at each AWOS location which is on an airport
- NWS Winds aloft (FD) have standard forecast times. Those times could be used.

### 7.1.1. Chief Benefits of the Website

From responses to this question, it does appear that the site is beneficial.

**Table 14: Chief Benefits of the Site**

| 8. What are the chief benefits of this website to you in your current position? Please be as specific as possible. | |
|---|---|
| Answer Options | Response Count |
| *No. of Respondents who Answered the Question* | 9 |

Responses:

- Situational awareness of weather for pilots
- It is another convenient tool in evaluating current and future weather conditions.
- We can use it today to help plan our fly-in visits to general aviation airports statewide.
- This site is potentially valuable for skiers seeking fresh cold snow, and seeking road information on highway routes. Unfortunately higher elevations holding resorts are not

represented. There is blank space where resorts could be included. As a reminder to carry appropriate survival gear....

- Not as much in my current position, but as a pilot, it's nice to have all this data in an easy to use format.
- Assisting in deciding whether or not to launch for a project at a distant location and allowing time necessary to arrive on schedule. Excellent resource!
- I use the site to help plan aviation flight plans.
- Quick brief aviation weather synopsis
- Getting aviation weather. Appreciate the different layers of info available.

### 7.1.1. Ways to Improve the Website

The responses to this question are generally self-explanatory.

**Table 15: Ways to Improve the Site**

| 9. Please also indicate in your own words how this website could be improved to better meet your needs. Consider information content, ease of use of the site, ability to understand what is presented and anything else that could make this site better. Be as specific as you can. | |
|---|---|
| Answer Options | Response Count |
| *No. of Respondents who Answered the Question* | 6 |

Responses:

- Winds and temperature aloft forecasts
- From an aviation perspective, forecast data is critical to flight planning. The more frequent the updates the safer the flight. Also, the system is robust in that it provides information in areas where there are not typically weather stations. The better we can link multiple weather data sources, the better we can plan flight activities, and by flight activities I am including emergency medical flights, firefighting, cargo and business aviation, not just typical commercial flights that use altitudes well above regional operational needs.
- I tried to use the route-making line but I got no action. I perhaps needed more instruction on how to create the line using the mouse.
- I appreciate the effort being used and with no previous awareness I still believe it will be very useful.
- Check with Wm. Hill regarding informal sources of information, from experienced observers scattered around the region who can give eyewitness reports of conditions.
- I will have to review over a longer period of time to discern if improvements are needed.
- Thank You

- Have the ability to go full screen if possible.
- Aviation tab, AWOS, Airport wx data, add link to last 3 (plus or minus) AWOS readings to get trend info. I appreciate actual METAR is included at bottom of Airport wx data page.
- Aviation tab, winds aloft, altitude choices are great. Want to know what time frame data is from. Is it actual (current) or forecast? NWS WD forecasts have standard forecast valid times. Choice of forecast valid times would be useful, to me.

# 8. COST–BENEFIT ANALYSIS

In this section, we describe the prospective costs and benefits of the prototype system developed as a product of this research. Previous literature has studied the benefit of weather information systems in certain specific cases. NOAA Economics (2009) provided a summary of research on the economic benefit of/cost mitigation by NOAA data and products related to ASOS. For example, it was mentioned that "the potential economic benefits from better forecasting of snow events at airports exceeds $600 million/year at U.S. airports (Adams et al., 2004)." "The economic benefit of the Terminal Convective Weather Forecast is $580 million/year as derived from airport delay-time reductions (Sunderlin and Paull, 2001)." "The economic benefits of the Integrated Icing Diagnostic Algorithm are $33.7 million/year, as derived from a reduction in air travel accidents (Paull, 2001)." "Integrated terminal weather system services provide economic benefits of $176 million/year from improved air traffic decision making, resulting in reduced gridlock and delays (Alan et al., 2001)."

More recently, based on user surveys, Ye et al. (2009) completed a cost and benefit analysis of the weather information for winter road maintenance. To quantify the benefit of aviation safety and efficiency, EUROCONTROL (2008) completed a cost and benefit analysis for Automatic Dependent Surveillance-Broadcast (ADS-B) implementation at Pescara Airport, but there is no detailed description of the methods and specifications of the models used.

Due to limited budget and time, we were unable to carry out a detailed and accurate cost and benefit analysis similar to those in the literatures above. Also, since the integrated weather system has not been deployed yet, our analysis in this section is preliminary and based on the current estimate and assumptions of the cost and potential benefit of the system. We first quantified the total costs of the system, which include initial development cost, maintenance and training cost, and user cost. Then we quantified the benefits of the system for users in three different categories: 1) airports, 2) heliports, and 3) ground weather stations.

## 8.1. Cost Analysis

We consider the project funding for research and development of the integrated weather system, the maintenance and training cost, and the cost to users.

### 8.1.1. Initial development cost

The initial investment in this product was the research and development costs Caltrans paid to fund this research carried out by WTI and SJSU. The funding for Phase I (this phase) was $200,000. Phase II of this project will focus on deployment of this system, for which the cost has not been determined but is estimated to be between $300,000 and $375,000.

### 8.1.2. Maintenance and training cost

There are two options to make the integrated AWOS/ASOS system available and maintain it for daily use at airports, heliports and ground stations. One is to use the setup currently running—i.e., hosted and managed by WTI. The other is to host it externally on a third-party server. Note that we preclude the option of Caltrans hosting in this analysis as that has generally been considered infeasible. If determined otherwise, that option may be considered further.

For the first option, the system costs include: hardware, software, maintenance, and training.

a. Hardware cost: The hardware cost is approximately $5000. The current hardware configuration is listed here: Dell PowerEdge 2900 III server, with Dual Quad Core Intel® Xeon®X5450 3.0GHz, 300 GB x 2 RAID hard drive, and 16 GB memory.
b. Software cost: There was no software cost because the system is based on free, open-source software, such as the Linux operating system, Apache HTTP Server, MySQL database, and PHP & Perl (LAMP configuration.)
c. Maintenance cost: The system is currently hosted and managed at WTI within the Montana State University College of Engineering. The maintenance cost is about $200 per month, or $2400 per year. This cost does not include staff support costs, which have typically been covered in the research and development contracts. These costs should be considered for support that falls outside the scope of the research and development contracts.
d. Training cost: It is estimated to cost approximately $2000 in travel and labor to have an expert from WTI go to California and give an 1-2 day annual training class for users in California, if necessary.

Therefore, the approximate cost of the system running for one year would be:

$5000 (one-time hardware fee) + $0 (software) + $2400 (maintenance fee) + $2000 (training) = <u>$9400</u>

In the second option considered, the system would use dedicated hosting at an external data center, and there would be no hardware cost or software cost. According to price information from a typical hosting web site (http://www.inmotionhosting.com/dedicated_servers.html), the monthly maintenance cost would be approximately $320. The hardware settings are listed as: Dell sever, Intel Xeon Quad Core 2.66GHz, 8GB memory, 250GB Disk, Raid 1, 2500GB monthly internet transfer, two-hour hardware replacement, 99.9% uptime, individual custom firewall, dedicated IP, etc.

The training cost is estimated to be the same as in the first option—$2000 per year.

Therefore, the total approximate cost for the second option would be:

$320 * 12 + $2000 = <u>$5840</u>.

### 8.1.3. User cost

Any user can use a computer with a standard web browser to access the integrated weather system. Therefore, the user cost of the integrated weather system is minimal.

## 8.2. Benefit Analysis

As of March 2009, there were 535 airports in California, including 252 public use airports (74 in Northern California) and 283 private use airports. Out of the 535 airports, only 109 are equipped with AWOS or ASOS. The majority of the AWOS and ASOS systems reside at the 31 commercial service airports and the busiest of the 219 general aviation airports. Commercial service airports are defined as providing scheduled passenger service with over 2,500 passenger enplanements a year.

In California, only 127 out of 535 airports (24%) and 121 out of 495 heliports (24%) are within five miles of an AWOS/ASOS station, and only 200 out of 535 airports (37%) and 262 out of 495 heliports (53%) are within 10 miles. If RWIS stations are also included, 148 out of 535 airports (28%) and 138 out of 495 heliports (28%) are within five miles, while 256 out of 535 airports (48%) and 317 out of 495 heliports (64%) are within 10 miles of a weather station (Table 16).

**Table 16: Proximity of Airport/Heliport Sites to AWOS/ASOS/RWIS Stations.**

| Distance to Nearest Weather Stations | Number of Airports = 535 | | Number of Heliports = 495 | |
|---|---|---|---|---|
| | within 5 miles | within 10 miles | within 5 miles | within 10 miles |
| **AWOS/ASOS** | 127 (24%) | 200 (37%) | 121 (24%) | 262 (53%) |
| **AWOS/ASOS + RWIS** | 148 (28%) | 256 (48%) | 138 (28%) | 317 (64%) |
| **AWOS/ASOS + WeatherShare** | 380 (71%) | 506 (95%) | 435 (88%) | 459 (93%) |

The accuracy of weather information is a problem for the airports without an AWOS/ASOS station because the nearest AWOS/ASOS station might be too far away to reflect the real situation at their airfields. Some small airports such as South County/San Martin Airport, and Eureka Municipal Airport only have a wind sock. These airports access the nearest AWOS or NWS weather information through the Internet or radio and report back to pilots when requested.

The integrated weather system serves to enhance pilot knowledge and safety by providing additional relevant weather information closer to the airport of operation. By integrating the data from 109 AWOS and ASOS sites with the 163 RWIS and other instrument sites in California, general aviation and private use airports and heliports can have access to more accurate weather information. Note that currently only 107 of the 163 RWIS in California are accessible by and integrated into WeatherShare. Currently, access to accurate weather information is very limited to these airports.

Based on information from Caltrans (2008), as of 2006, there were 23,854 active general aviation and air-taxi aircraft and 63,843 pilots in California. 80 percent of the air traffic operations in California are considered general aviation. General aviation is any type of civil aircraft operation that is not guided by 14 *Code of Federal Regulations* (CFR) Parts 121, 129, and 135, which are referred to as "commercial aviation" operations. General aviation aircraft and airports are not always supplied with weather monitoring equipment as advanced as commercial aircraft and airports. This is largely due to the cost of each system.

The users of the integrated weather system can be classified into three general categories: airports, heliports and ground transportation. Our benefit analysis was carried out for these three types of users separately.

### 8.2.1. Airports

We use two methods to calculate the benefit of the integrated weather system to airports or airport users.

#### 8.2.1.1. Method 1

For the first method, we compare the costs of the system with the costs of installing AWOS or ASOS at airports, and we claim the cost savings of using the system to be the value of its benefit. We must stress, though, that the system is not a replacement for a local AWOS or ASOS weather station. It may be used, at the discretion of aviation users, in the absence of an installed weather station and in conjunction with other information sources, if an AWOS or ASOS installation is infeasible due to costs or other constraints. The installation cost and annual maintenance cost for ASOS and AWOS are listed in Table 17.

**Table 17: Costs of Various Weather Systems that Currently Exist in the Aviation Industry**

| Weather System | Installation Cost ($) | Annual Maintenance Cost ($) |
|---|---|---|
| ASOS | 300,000 | 27,000 |
| AWOS | 14,400 – 3,800* | 4,200 |
| SUPER AWOS | 76,000 | 1,000 |

*Sources: All Weather Inc. (2010).*

*Depending on the type of AWOS and sensors available

The installation cost of an AWOS depends on the type of sensors needed, while the annual maintenance cost is fixed.

We note that Federal Aviation Administration (FAA) has funding available for an AWOS purchase by qualified airports. However, for an airport to qualify for funding it must be publicly owned, or privately owned but designated by FAA as a reliever, or privately owned but having scheduled service and at least 2,500 annual enplanements (FAA, 2007). (A relief airport provides relief in terms of increased capacity for a service area.) The airport must also be in the National Plan of Integrated Airport Systems, which includes 74 airports in Northern California. The majority of smaller airports and heliports are not qualified for the FAA grants and therefore must rely on airport-generated revenue or other sources for installation of an AWOS.

Based on the listed costs of ASOS and AWOS, without regard to financial support from the FAA, the cost difference of using the integrated weather system at any airport will be at least $1000 each year for each airport. Again, we do not pose the system as a replacement for AWOS or ASOS, but rather a source of information that could be used in the absence of an AWOS or ASOS.

#### 8.2.1.2. Method 2

The second method used to quantify the benefit of the system was to determine how the system can improve the safety and efficiency of airport operations.

To quantify the benefit in terms of safety improvement, we first need information about weather-related accidents at smaller airports due to inaccurate or no weather information.

Instrument Meteorological Conditions (IMC) conditions are defined as “meteorological conditions expressed in terms of visibility, distance from cloud, and ceiling less than the minimums specified for Visual Meteorological Conditions (VMC)” (NTSB, 2009a). Accidents occurring during a reduction of visibility, whether due to a low ceiling, obscuring phenomenon or fog, were among the most fatal. In 2005, only 16 percent of accidents that occurred in visual conditions (i.e., VMC) resulted in a fatality, but 65 percent of accidents in instrument conditions (i.e., IMC) were fatal. Causes of accidents in IMC conditions include pilot disorientation, unfamiliarity with the area, collisions with obstacles or terrain and loss of control. Although instrument conditions were in effect for only 6 percent of all accidents, 19 percent of fatal general aviation accidents in 2005 occurred under IMC. We do note, though, that visibility measures in the system are generally reported only from AWOS or ASOS sites.

General aviation aircraft are typically smaller and slower compared to air-carrier aircraft, and they are more vulnerable to adverse weather. At the same time, general aviation aircraft do not have as much access to weather information, such as radar, during flight as an air-carrier does. In 2004, approximately 83 percent of all weather-related accidents occurred to aircraft operating under FAR 91, or “general aviation” operations. A general aviation pilot typically relies on weather reports from nearby airports and visual cues, which could be dangerous for a cross-country flight through rural areas with rough terrain, where weather information may be inaccessible. The integrated weather system can provide more access points of weather information to assist pilots planning their cross-country flight and eliminate unknown weather hazards.

Every year, the National Transportation Safety Board (NTSB) studies the causes of general aviation accidents in a publication called the *NTSB Annual Review of U.S. General Aviation Accident Data*, which describes how weather can be a contributing factor in causing an accident. In 2005, weather was a contributing factor in approximately 18 percent (309) of all general aviation accidents in the United States. Three percent of all general aviation accidents were caused solely by the weather (NTSB, 2009a).

Table 18 shows the different types of weather-related accidents involving general aviation aircraft, and their corresponding fatalities for the United States in 2005 according to NTSB (2009a).

**Table 18: General Aviation Weather Accident in 2005**

| Weather Condition | Accidents | Fatalities | Weather Condition | Accidents | Fatalities |
|---|---|---|---|---|---|
| Crosswind | 68 | 1 | Snow | 4 | 4 |
| Gust | 57 | 6 | Variable Wind | 3 | 0 |
| Tailwind | 48 | 3 | Haze/Smoke | 3 | 3 |
| High Density Altitude | 33 | 5 | Temperature High | 2 | 0 |
| Low Ceiling | 33 | 30 | Whiteout | 2 | 1 |
| Carburetor Icing Conditions | 18 | 0 | Unfavorable Wind | 2 | 1 |
| Fog | 18 | 10 | Dust Devil/ Whirlwind | 2 | 0 |
| Downdraft | 15 | 0 | Turbulence, Clear Air (CAT) | 1 | 0 |
| Icing Conditions | 12 | 5 | Mountain Wave | 1 | 1 |
| Clouds | 10 | 7 | Turbulence in Clouds | 1 | 0 |
| High Wind | 10 | 2 | Thunderstorm, Outflow | 1 | 0 |
| Obscuration | 7 | 7 | Below Approach/Landing Minimums | 1 | 1 |
| Windshear | 6 | 0 | Drizzle/Mist | 1 | 1 |
| Rain | 6 | 4 | Microburst/Dry | 1 | 1 |
| Thunderstorm | 5 | 4 | Other | 1 | 0 |
| Turbulence | 5 | 2 | Lightning Strike | 1 | 0 |
| No Thermal Lift | 5 | 0 | **Total** | **309** | **67** |

Source: NTSB (2009a).

From the table above, we can see that the top three weather-related factors in general aviation accidents in 2005 involved wind: “crosswind,” “gusts,” and “tailwind.” These were cited as a cause/factor in 173 accidents, and 10 of those accidents were fatal. Among fatal general aviation accidents, the three most frequently cited weather factors were related to conditions that resulted in reduced visibility, including “low ceiling,” “fog,” and “clouds.”

One goal of the integrated weather system is to reduce weather-related accidents by providing accurate, integrated weather information to rural airports and heliports and thus reduce the impact of weather on general aviation aircraft accidents.

Table 19 shows the standard “value of lost life and injuries.” Since the system has not been fully deployed, it is not clear yet how many accidents could be reduced or mitigated. However, even if one severe injury can be avoided each year in the state of California, the cost savings would be more than $1 million per year.

**Table 19: Values of Lost Life and Injuries.**

| AIS Code | Injury Severity Level | Avoided Cost of Injury | Selected Injuries |
|---|---|---|---|
| AIS 1 | Minor | $11,600 | Superficial abrasion or laceration of skin; digit sprain; first-degree burn; head trauma with headache or dizziness (no other neurological signs) |
| AIS 2 | Moderate | $89,900 | Major abrasion or laceration of skin, cerebral concussion (unconscious less than 15 minutes); finger or toe crush/amputation; closed pelvic fracture with or without dislocation |
| AIS 3 | Serious | $333,500 | Major nerve laceration; multiple rib fracture (but without flail chest); abdominal organ contusion; hand, foot, or arm crush/amputation |
| AIS 4 | Severe | $1,087,500 | Spleen rupture; leg crush; chest-wall perforation; cerebral concussion with other neurological signs (unconscious less than 24 hours) |
| AIS 5 | Critical | $4,422,500 | Spinal cord injury (with cord transaction); extensive second or third-degree burns; cerebral concussion with severe neurological signs (unconscious more than 24 hours) |
| AIS 6 | Fatal | $5,800,000 | Fatalities and injuries which, although not fatal within the first 30 days after an accident, ultimately result in death |

*Sources: Office of the Secretary of Transportation Memorandum (2008).*

Improvement of operation efficiency is another benefit of the system. As we mentioned at the beginning of this chapter, there are case studies available that prove that accurate weather information reduces delay and congestion, and increases airport capacity. According to the FAA Research, Engineering and Development Advisory Committee, adverse weather accounts for 70 percent of all National Aviation System airspace delays. According to Gloria (2003), weather-related delays, accidents and unexpected operating expenses cost the aviation industry an estimated $3 billion a year in the United States.

The integrated weather system combines reports from different meteorological instruments to provide a more detailed weather observation for that airport or heliport. For instance, if Eureka/Arcata Airport's AWOS was reporting IMC conditions, then Eureka Municipal Airport would also be reported in IMC if it got its weather information only from Eureka/Arcata Airport, even though Eureka Municipal could be in VMC. Without the integrated weather system, pilots operating in and out of Eureka Municipal Airport might have incomplete weather information, which could cause unnecessary flight delays, cancelations and diversions. On the other hand, if the Eureka Municipal Airport was actually under IMC but reported as VMC based on information from Eureka/Arcata Airport, the inaccurate weather information might cause serious safety problems.

The integrated weather system can provide more weather information and reduce delay at those airports with limited access to weather information. The standard passenger's value of time is described in the table below. While it is not clear how much delay can be avoided by using the system since it has not yet been deployed, if we assume that it could save one minute for 1,000 passengers each day in California, then the total cost savings for passengers would be at least $200,000 per year. That would amount to one-third of the total initial development costs, and be much higher than the total annual maintenance costs of the system.

**Table 20: Standard Passengers' Value of Time**

| Category | Recommended Value per Hour | Sensitivity Range | |
|---|---|---|---|
| | | Low | High |
| **Commercial:** | | | |
| Personal | $23.30 | $20.00 | $30.00 |
| Business | $40.10 | $32.10 | $48.10 |
| All purposes | $28.60 | $23.80 | $35.60 |
| **General Aviation:** | | | |
| Personal | $31.50 | (No Recommendation) | |
| Business | $45.00 | | |
| All purposes | $37.20 | | |

*Source: Office of the Secretary of Transportation Memorandum (2003).*

The standard airline cost is listed in Table 21 below. For general aviation aircraft, if we assume that 100 block hours of aircraft delay can be reduced annually through more detailed weather information disseminated by the system, then the cost savings for general aviation would be $139,000 per year.

**Table 21: Airline Cost Based on Block Hours**

| FY09$ | Variable Cost | | | Fixed Cost per Block Hour | Total Per Block Hour |
|---|---|---|---|---|---|
| | Per Airborne Hour | Per Ground Hour | Per Block Hour | | |
| Air Carrier – Passenger | $3,771 | $1,899 | $3,471 | $800 | $4,272 |
| Air Carrier – Cargo | $7,388 | $3,721 | $6,801 | $1,834 | $8,635 |
| Air Carrier – TAF | $4,045 | $2,037 | $3,724 | $878 | $4,602 |
| Air Taxi – TAF | $1,059 | $533 | $975 | $577 | $1,551 |
| General Aviation | $589 | $297 | $542 | $848 | $1,390 |
| Military | $7,404 | $3,729 | $6,816 | $1,838 | $8,654 |

*Sources: GRA, Incorporated (2007).*

### 8.2.2. Heliports/helipads

The integrated weather system will not replace the ASOS/AWOS stations. Instead, the system can be taken as a complement to existing AWOS or ASOS, particularly in areas that are not served locally with an AWOS or ASOS. Therefore, this system will be very useful to heliport and helipad users, because AWOS or ASOS systems are not located at these facilities. It will also be very beneficial to helicopters such as air ambulances, which often need to land on highways, a parking lot, a field, or a mountain in order to pick up a patient. There likely will not be any nearby AWOS or ASOS at these locations. However, the integrated weather system can bring weather data from sensors all over the state. Such weather information is very useful for pre-flight planning, and can provide guidance for landing.

Currently, there are approximately 495 permitted heliports in California, including 152 hospital heliports, 192 corporate heliports, 51 police heliports, 41 fire heliports, 2 commuter heliports and 57 private heliports. The benefit of the integrated weather system is generally to improve the safety of helicopter operations at heliports/helipads, or at some specific locations even without heliport/helipad facilities. In this section, we use Emergency Medical Services (EMS) as an example to analyze the benefit of the integrated weather system to helicopter operations.

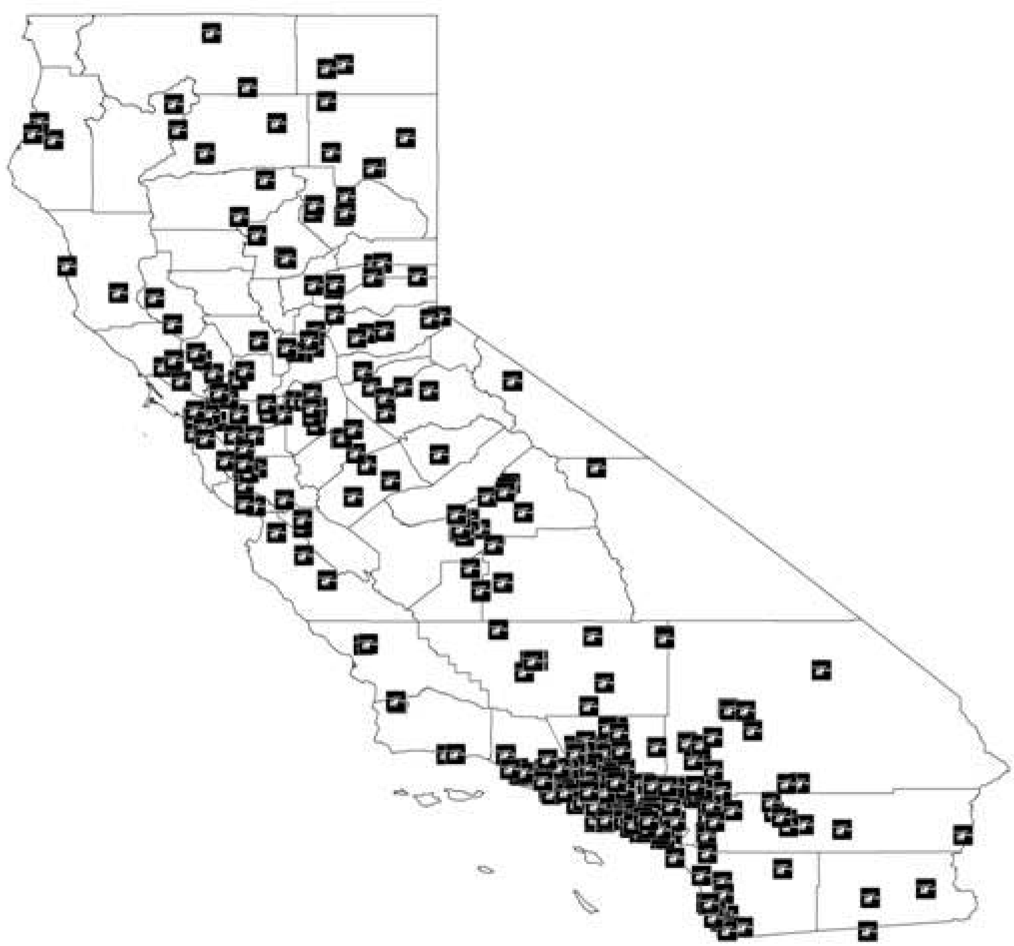

**Figure 21: Heliports in California**

Several studies have shown EMS helicopter operations to be effective in saving lives. For example, Connell and Patten (1993) claimed that immediate care in the first hour after a serious injury can reduce the mortality rate by 50 percent. EMS helicopter operations have boomed during the last 20 years because of their life saving effectiveness. There are about 5,800 heliports/helipads in the United States, and approximately 15,000 patients are transported in an emergency rescue helicopter in the country annually. Based on the proportionality assumption, we estimate that at least 1,000 patients each year are transported by emergency rescue helicopters in California.

Ambulance and rescue helicopters pose a greater risk for an accident than any other helicopter operation because they often fly in adverse weather and operate near areas such as forest roads, rocky cliffs, and mountainous terrain, with little or no source of weather information. According to the NTSB, helicopter EMS accident rates are 3.5 times higher than other non-scheduled helicopter operations. At present, there were approximately 840 emergency medical service helicopters operating in the United States (FAA, 2009). Between the mid-1990s and the early 2000s, the accident rates for EMS helicopters nearly doubled; there were nine accidents in 1998, and 15 accidents in 2004, five of which resulted in 17 fatalities. The higher accident rate may be due to terrain and object collisions during unexpected IMC, and pilot disorientation. NTSB (2009b) reports that there were 55 EMS accidents between January 2002 and January 2005 that involved 41 helicopters and 14 airplanes. There were 12 EMS helicopter accidents in 2008, which resulted in 28 deaths and 8 injuries, according to the Nolan Law Group (2009).

There are few systematic or quantitative studies on the impact of weather information availability on the accidents of EMS helicopters. NTSB (2009b) reports that “13 of 55 accidents may have benefited from use of NVIS (Night Vision Imaging Systems),” and “17 of 55 accidents may have been prevented with TAWS (Terrain Awareness and Warning System).” The FAA has funded the development and implementation of a “graphical flight planning tool for ceiling and visibility assessment along direct flights in areas with limited available surface observation capability” and claims that the response from the users are very favorable (FAA, 2009).

It is expected that the integrated weather system, providing weather information from various sources, can provide a better image of the weather occurring at the EMS helicopter’s destination or origin, which will reduce the number of accidents caused by unexpected weather. It should be noted, though, that the system does not include functionality to assist with night visibility. Based on the information in Table 19, if one moderate injury could be avoided through the use of the integrated system, the savings would be $89,900. If one fatal accident could be avoided, the benefit of the integrated system would be $5,800,000, which would be much more than the initial development cost and the maintenance cost of the system.

More quantitative studies can be carried out after the installation of the system, so that operations before and after implementation can be compared and input from users can be collected for analysis.

### 8.2.3. Ground transportation

The integrated weather information system can also provide benefits to ground transportation. As a complement to RWIS, the system provides surface transportation weather information useful for maintaining and operating California’s highways. RWIS provides real-time weather and road conditions for developing more effective and efficient treatment strategies in winter maintenance, and has become an essential component to winter maintenance and snow removal operations. The implementation of RWIS requires a large capital investment and dedicated resources for procurement, maintenance, effective coordination, and data dissemination. The cost of deploying a single RWIS is approximately $100,000 per site (Abernethy, 2003), and the monthly maintenance cost is about $450 to $900 per site (Albert, 2002). Due to the cost, and limited funds available to state DOTs, the deployment of RWIS has been limited with deployments prioritized to trouble spots with significant winter conditions. As of April 2009, there were 163 RWIS sites in California (Figure 22). Figure 23 shows the locations of all current weather stations used by the integrated system, including 3,271 surface real-time weather stations from WeatherShare and 86 of the 109 AWOS/ASOS stations from the NWS. Note that the NWS web site lists 109 AWOS/ASOS stations, but only 86 stations have feed data through the Internet; the others are only accessible through radio. The integrated system also provides a collection of forecast weather data such as air temperature, humidity, cloud cover, probability of precipitation, amount of precipitation, weather type, and wind direction and speed from NDFD, warnings and advisories for severe thunderstorms, tornado and winter storm watches and warnings, as well as blizzard warnings, snow advisories, and flood watches and warnings issued by the NWS. By integrating AWOS/ASOS data as well as other current and forecast surface weather data, the system provides an integrated picture of weather for winter maintenance decision making.

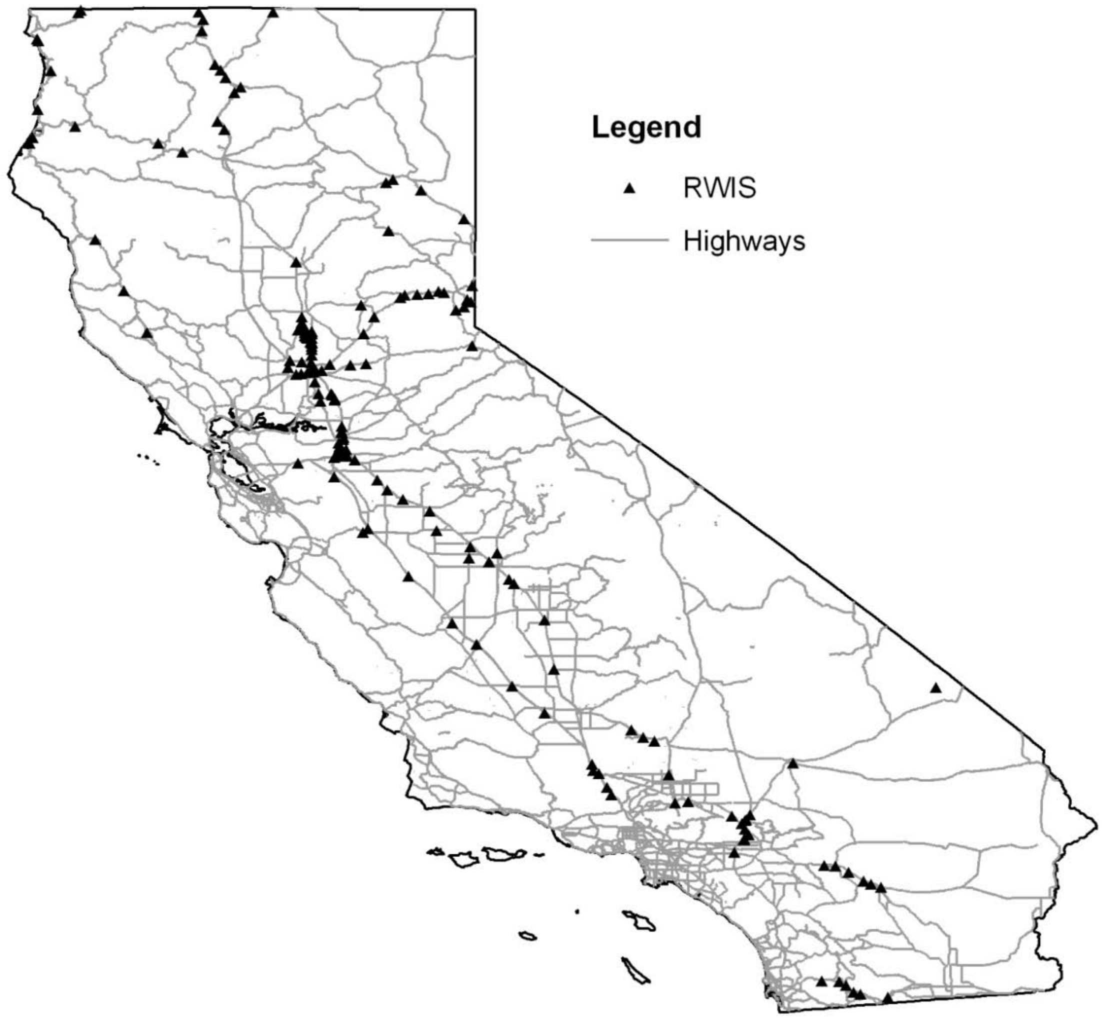


**Figure 22: Caltrans RWIS Locations in California**

Source: Chu, 2009.

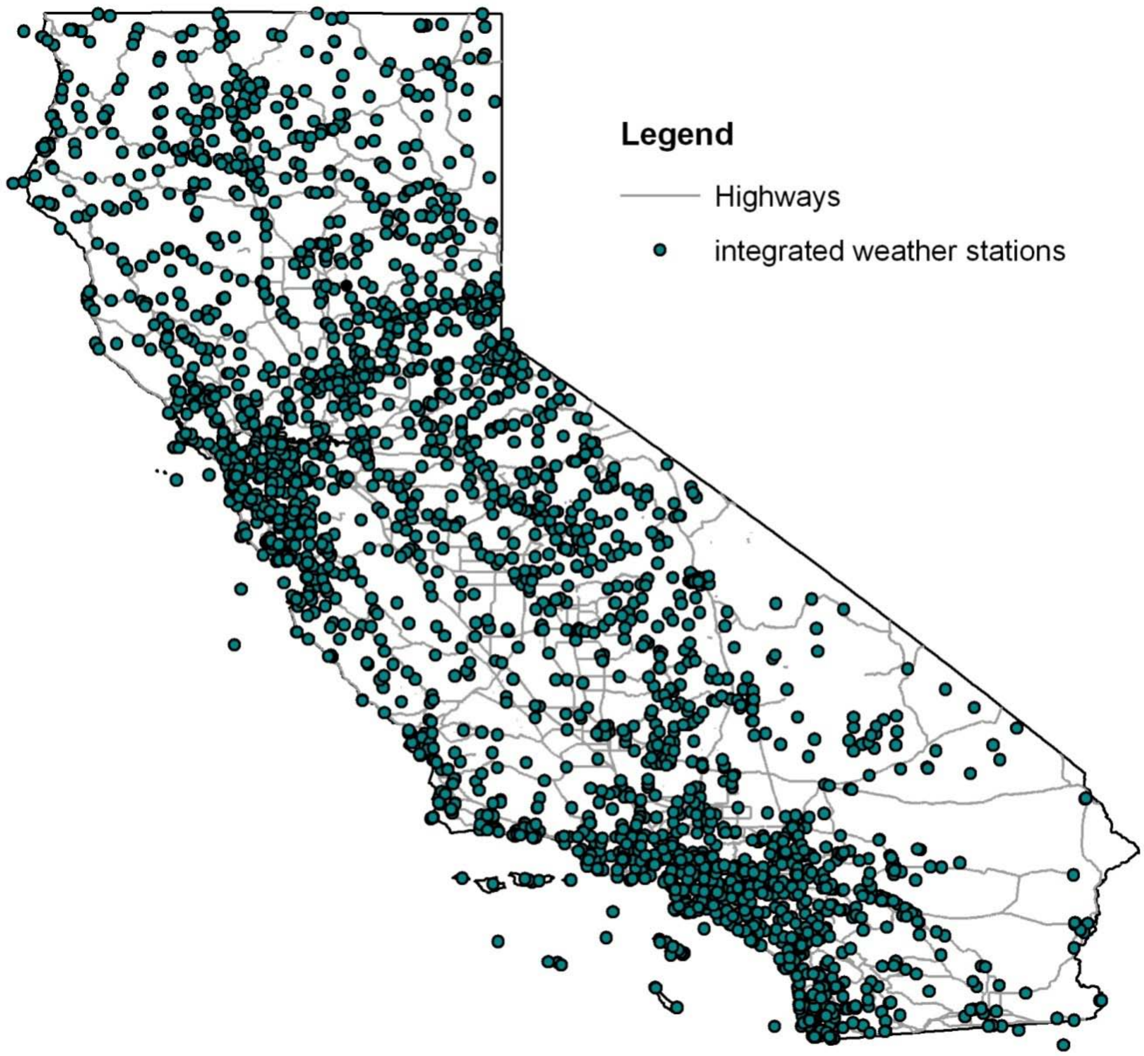


**Figure 23: All Integrated Weather Stations Locations in California**

The benefits in terms of improved winter maintenance can be quantified in two ways: cost savings as a result of better practices or reduced level of services (LOS), and the indirect benefits resulting from enhanced safety and mobility for surface transportation. According to a cost–benefits study of Utah DOT winter maintenance, the value and additional savings potential of the Utah DOT weather service were 11 percent to 25 percent and 4 percent to 10 percent of the Utah DOT labor and materials cost for winter maintenance, respectively (Strong, 2008). This highlights the potential benefits of using improved weather information to direct winter maintenance activities. Based on data from National Cooperative Highway Research Program (NCHRP) Synthesis 344 report (2005), the average rural winter maintenance cost per lane mile for 2002/03 for Nevada, Oregon and Washington states were \$300, \$1000, and \$1500, respectively. For Caltrans, there is no such data available. Here we assume the average rural winter maintenance cost per lane mile for Caltrans to be about \$1000. With Caltrans maintaining approximately 173,372 lane-miles of rural highways (FHA, 2008), even a one percent cut in maintenance costs because of improved weather service data may save over \$1,700,000 annually. The integrated weather system could also promote safety and mobility of surface transportation system. According to data from Road Weather Management Programs, Office of Operations, FHWA (2009), each year nearly 6,600 fatal crashes, 1.5 million weather-related crashes (crashes occurring in the presence of adverse weather and/or slick pavement) occur in the United States, resulting in 670,000 injuries and 7,400 fatalities. The economic cost due to personal injury, loss of life, and property damage is estimated at $42 billion annually. For weather impacts on mobility, the estimated traffic delays from adverse weather are nearly 1 billion person-hours per year, which cause degraded productivity, reliability, and user experience of the surface transportation system. For trucking companies and other commercial vehicle operators alone, the estimated cost of weather-related delay ranges from $2.2 billion to $3.5 billion annually. Considering all of those significant costs related to weather-related crash and delay, there will likely be some indirect benefits for improved safety and mobility by using the integrated weather information system in winter maintenance decision making.

In addition, the integrated weather system can help to identify the problematic RWIS Environmental Sensor Station (ESS) sensors. RWIS has a poor reputation regarding reliability and accuracy: data is not always available, observed conditions frequently do not correlate with data, and there is no independent way to ensure data integrity (Ken, 2009). With the integration of nearby weather station data from AWOS/ASOS and other sources, quality control processes such as Spatial Consistency Check can be implemented to flag problematic sensor readings. This can provide a better way for state DOT ESS administrators or end users to spot sensors that require additional investigation. Especially for remote RWIS sites, this could help to save time and money if the remote problematic RWIS ESS sensor could be identified without unnecessary site visits.

Further, the project team has looked at additional cost-benefits related to RWIS maintenance. The success of winter road maintenance relies on accurate and effective RWIS operations, which requires routine maintenance of the system. The proper calibration of RWIS surface sensors is critical to operation because calibration will drift over time and with traffic (Ken, 2009). Regarding the maintenance services for RWIS station hardware, state DOTs either get into a service contract with the vendor, or send their own state personnel to the vendor to receive service training. The training costs approximately $5000 and lasts for two days (Albert, 2002). Some state DOTs choose in-house maintenance primarily because of the cost, and poor service received from some vendors. Other states enter into a service contract with the vendor, considering the training cost of DOT personnel and the time it takes to develop the skills and familiarity with the system necessary for effective trouble shooting. Either way, the effectiveness of maintenance depends upon the amount of resources and time that each agency is willing to allocate to its system. Considering AWOS and ASOS have a similar suite of sensors as RWIS, and require similar calibration and maintenance but have a better reputation regarding reliability and accuracy, there could be some efficiencies derived from using the same entities that provide installation, calibration and maintenance for AWOS and ASOS to provide a similar service for RWIS.

# 9. RECOMMENDATIONS

Based on results of the survey and the cost–benefit analysis, the system was found to be a valuable tool for end users, as well as cost-beneficial.

The next steps for the project will be to address enhancements recommended by stakeholders and begin Phase II. The goal of Phase II is to prepare for full corporate deployment of the integrated system in California. The objectives are:

1. Develop a business case to help Caltrans determine whether and how to proceed with full deployment.

   The project team, in cooperation with Caltrans, will conduct a business case analysis and produce documentation for use in a Feasibility Study Report (FSR). We will develop partnerships and plans for long-term maintenance and management of the system.

2. Conduct further system development to expand data sources; improve usability, effectiveness, reliability and scalability; and enhance the system with unique and useful functionality.

3. Address institutional issues to best foster the relationships necessary for cooperative maintenance and deployment arrangements.

A number of deliverables were produced during the course of this effort. These included:

- Final Report
- Quarterly Reports
- Cost–Benefit Analysis Summary
- Evaluation Summary
- Laboratory Prototype Survey and Feedback, and Implications
- Initial Requirements Summary
- Initial Concept Document
- Initial Acquisition, Maintenance and Related Cost Summary
- Initial Station and Air Field / Heliport Site Analysis Summary
- Literature Review Summary

These deliverables were combined in several cases and the documents produced were:

- Integration of Aviation Automated Weather Observation Systems (AWOS) with Roadside Weather Information Systems (RWIS)
- Literature Review
- Initial Acquisition, Maintenance and Related Cost Summary for AWOS/ASOS and RWIS
- Final Report

These reports, along with the prototype system that was developed are the primary products of this research and development effort.

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# 11. APPENDIX

Integration of Automated Weather Observing System (AWOS) with Road Weather Information System (RWIS) Prototype System User Survey

This survey is being undertaken by the Western Transportation Institute, Montana State University, and is sponsored by the Division of Aeronautics and the Division of Research and Innovation of California Department of Transportation, to obtain information about your use of the Integration of Automated Weather Observing System (AWOS) with Road Weather Information System (RWIS) prototype system.

If you would like to participate, please take a few minutes and answer the questions below. You may provide this survey to others in your agency / organization that use the prototype system. Participation is voluntary. By taking the survey, you consent to the use of your responses for the objective stated above.

Your contact information will only be used by the researchers for the purposes of this study. The researchers will not contact you for any other reason and your contact information will not be released or shared for any other reason. If you have any questions concerning your rights as a human subject and/or the use of your contact information, please contact:

Institutional Review Board
Montana State University
P.O. Box 173610
Bozeman, MT 59717-3610
Phone: (406) 994-6783
Fax: (406) 994-4303

Survey directions:

In order to progress through this survey, please use the navigation links presented on the survey pages:

- Use the Next button to continue to the next page.
- Use the Previous button to return to the previous page.
- Use the Exit the Survey link to exit the survey. Your responses will not be saved.
- Use the Submit button on the last page to submit your survey responses.

Note: Clicking the Back button in your browser before a page is completed will clear all data entered on the current page. Your responses will only be saved upon completion of the survey. You may not leave a survey session and start up again where you left off.

Please click the Next button to proceed to the survey:

1. Please enter the contact information.

Name: ____________________________________________________________

Position/Title: ______________________________________________________

Organization: _______________________________________________________

Telephone: _________________________________________________________

E-mail: ____________________________________________________________

2. How often do you visit the AWOS with RWIS system site for information?

- ☐ Website is open all the time
- ☐ Hourly
- ☐ Daily
- ☐ Weekly
- ☐ Monthly
- ☐ Not at all
- ☐ Other (please specify): ________________________________________

3. When do you use the information? (check all that are applicable)

- ☐ Daytime hours
- ☐ Nighttime hours
- ☐ Under changing conditions only
- ☐ During incident conditions (storm/fire etc)
- ☐ When Supervisor on-duty only
- ☐ When Supervisor off-duty
- ☐ Other (please specify): ________________________________________

4. Now we would like you to rate the usefulness of the data on the Website that you have *used* at least once. For each feature that you have *not* used, please <u>indicate </u>whether you

were aware of this feature before taking this survey (Please make a single selection for each data element.)

| Surface Layer Recent Conditions | Use Data | | | Don't Use Data | |
|---|---|---|---|---|---|
| | **Very Useful** | **Somewhat Useful** | **Not Very Useful** | **Aware of it** | **Not Aware of it** |
| a. Station locations | ☐ | ☐ | ☐ | ☐ | ☐ |
| b. Air Temperature | ☐ | ☐ | ☐ | ☐ | ☐ |
| c. Wind direction & speed | ☐ | ☐ | ☐ | ☐ | ☐ |
| d. Relative Humidity | ☐ | ☐ | ☐ | ☐ | ☐ |
| e. Precipitation Last Hour | ☐ | ☐ | ☐ | ☐ | ☐ |
| f. Precipitation Last 24 Hours | ☐ | ☐ | ☐ | ☐ | ☐ |
| g. NWS Observed 24 Hour Precip | ☐ | ☐ | ☐ | ☐ | ☐ |
| h. RWIS specific information such as Pavement Conditions | ☐ | ☐ | ☐ | ☐ | ☐ |
| i. Station detail bubble information | ☐ | ☐ | ☐ | ☐ | ☐ |

| Surface Layer NDFD Forecast Data | Use Data | | | Don't Use Data | |
|---|---|---|---|---|---|
| | **Very Useful** | **Somewhat Useful** | **Not Very Useful** | **Aware of it** | **Not Aware of it** |
| a. Air Temperature | ☐ | ☐ | ☐ | ☐ | ☐ |
| b. Wind direction & speed | ☐ | ☐ | ☐ | ☐ | ☐ |
| c. Wind Gust Speed and direction | ☐ | ☐ | ☐ | ☐ | ☐ |
| d. Relative Humidity | ☐ | ☐ | ☐ | ☐ | ☐ |
| e. Sky cover | ☐ | ☐ | ☐ | ☐ | ☐ |

| | | | | | |
|---|---|---|---|---|---|
| f. 12-hour Probability of Precipitation | ☐ | ☐ | ☐ | ☐ | ☐ |
| g. 6-hour Amount of Precipitation | ☐ | ☐ | ☐ | ☐ | ☐ |
| h. Snow | ☐ | ☐ | ☐ | ☐ | ☐ |
| i. Weather | ☐ | ☐ | ☐ | ☐ | ☐ |
| j. NDFD forecast data provided at 3 hour intervals for next 24 hours | ☐ | ☐ | ☐ | ☐ | ☐ |

| **Surface Layer NWS Alert** | **Use Data** | | | **Don't Use Data** | |
|---|---|---|---|---|---|
| | **Very Useful** | **Somewhat Useful** | **Not Very Useful** | **Aware of it** | **Not Aware of it** |
| a. Color-coded and graphic display of NWS alert | ☐ | ☐ | ☐ | ☐ | ☐ |
| b. Alert detail bubble information | ☐ | ☐ | ☐ | ☐ | ☐ |

| **Surface Layer Caltrans CCTV** | Use Data | | | Don't Use Data | |
|---|---|---|---|---|---|
| | **Very Useful** | **Somewhat Useful** | **Not Very Useful** | **Aware of it** | **Not Aware of it** |
| a. CCTV images | ☐ | ☐ | ☐ | ☐ | ☐ |

| **Aviation Layer** | Use Data | Don't Use Data |
|---|---|---|

| | Very Useful | Somewhat Useful | Not Very Useful | Aware of it | Not Aware of it |
|---|---|---|---|---|---|
| a. AWOS/ASOS (METAR) data | ☐ | ☐ | ☐ | ☐ | ☐ |
| b. Encoded Pilot Reports (PIREPS) | ☐ | ☐ | ☐ | ☐ | ☐ |
| c. Terminal Aerodrome Forecasts (TAF) | ☐ | ☐ | ☐ | ☐ | ☐ |
| d. Radar: NWS CONUS Merged Reflectivity Composite | ☐ | ☐ | ☐ | ☐ | ☐ |
| e. Satellite: IR Temperature | ☐ | ☐ | ☐ | ☐ | ☐ |
| f. Satellite: Water Vapor | ☐ | ☐ | ☐ | ☐ | ☐ |
| g. Satellite: Visible | ☐ | ☐ | ☐ | ☐ | ☐ |

| Aviation Layer Wind Aloft | Use Data | | | Don’t Use Data | |
|---|---|---|---|---|---|
| | **Very Useful** | **Somewhat Useful** | **Not Very Useful** | **Aware of it** | **Not Aware of it** |
| a. 3000 ft MSL (900mb) | ☐ | ☐ | ☐ | ☐ | ☐ |
| b. 6000 ft MSL (800mb) | ☐ | ☐ | ☐ | ☐ | ☐ |
| c. 9000 ft MSL (725mb) | ☐ | ☐ | ☐ | ☐ | ☐ |
| d. 12000 ft MSL (650mb) | ☐ | ☐ | ☐ | ☐ | ☐ |
| e. 15000 ft MSL (575mb) | ☐ | ☐ | ☐ | ☐ | ☐ |

| Aviation Layer Temperature Aloft | Use Data | | | Don't Use Data | |
|---|---|---|---|---|---|
| | **Very Useful** | **Somewhat Useful** | **Not Very Useful** | **Aware of it** | **Not Aware of it** |
| a. 3000 ft MSL (900mb) | ☐ | ☐ | ☐ | ☐ | ☐ |
| b. 6000 ft MSL (800mb) | ☐ | ☐ | ☐ | ☐ | ☐ |
| c. 9000 ft MSL (725mb) | ☐ | ☐ | ☐ | ☐ | ☐ |
| d. 12000 ft MSL (650mb) | ☐ | ☐ | ☐ | ☐ | ☐ |
| e. 15000 ft MSL (575mb) | ☐ | ☐ | ☐ | ☐ | ☐ |

5. Now we would like you to rate the usefulness of the *features* on the Website that you have *used* at least once. For each feature that you have *not* used, please indicate whether you were aware of this feature before taking this survey (Please make a single selection for each feature.)

| | **Use Features** | | | **Don't Use Features** | |
|---|---|---|---|---|---|
| | **Very Useful** | **Somewhat Useful** | **Not Very Useful** | **Aware of it** | **Not Aware of it** |
| a. Google Map display & zoom function | ☐ | ☐ | ☐ | ☐ | ☐ |
| b. Color-coded weather information and graphic representation | ☐ | ☐ | ☐ | ☐ | ☐ |
| c. Historical data access for surface weather stations through screen display | ☐ | ☐ | ☐ | ☐ | ☐ |
| d. Historical data access for surface weather stations through CSV file export | ☐ | ☐ | ☐ | ☐ | ☐ |
| e. Having the NDFD forecast data mapped to highway mileposts at one mile intervals in addition to the background raster. | ☐ | ☐ | ☐ | ☐ | ☐ |

| | | | | | |
|---|---|---|---|---|---|
| f. Different data layers switching using tab display and radio button | ☐ | ☐ | ☐ | ☐ | ☐ |
| g. Auto refresh web page every 3 minutes | ☐ | ☐ | ☐ | ☐ | ☐ |

6. Based on your experience using the site please evaluate the site in terms of the following aspects – indicate your level of agreement with these statements:

| | **Strongly Agree** | **Somewhat Agree** | **Neither Agree nor Disagree** | **Somewhat Disagree** | **Strongly Disagree** |
|---|---|---|---|---|---|
| a. The site is well organized and user friendly | ☐ | ☐ | ☐ | ☐ | ☐ |
| b. I would like to see ***NDFD forecast*** information for more than 24 hours | ☐ | ☐ | ☐ | ☐ | ☐ |
| c. I would like to see more/different ***Radar*** images (please specify in comments section) | ☐ | ☐ | ☐ | ☐ | ☐ |
| d. I would like to see more/different ***Wind/Temperature aloft*** at higher altitude (please specify in comments section) | ☐ | ☐ | ☐ | ☐ | ☐ |
| e. I would like to see ***Wind/Temperature aloft*** at time intervals further out than 1 hour (please specify in comments section) | ☐ | ☐ | ☐ | ☐ | ☐ |

7. What additional weather information would you like to have, which is not available currently at this site? (Please specify the type, format, frequency of updating, accuracy)

8. What are the chief benefits of this website to you in your current position? Please be as specific as possible.

9. Please also indicate in your own words how this website could be improved to better meet your needs. Consider information content, ease of use of the site, ability to

understand what is presented and anything else that could make this site better. Be as specific as you can.