Coping with Adverse Winter Weather

Emerging Capabilities in Support of Airport and Airline Operations

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Winter weather has the potential to significantly disrupt airport and airline operations yielding flight delays, diversions, and cancellations.[1, 2, 3, 4] The impacts thereof may be felt throughout the National Airspace System (NAS) and notably beyond the duration of a winter weather event, as recovery doesn't occur immediately. Moreover, in some situations hazardous conditions created by freezing rain, slush, snow, drifting snow, or ice may lead to aircraft incidents or accidents.[5, 6, 7]

Safety and efficiency of flight operations are the primary concerns of any operator, but they need special attention during winter conditions. Both hinge on timely and accurate detection and predictions of weather and anticipated implications for an airport's capacity. Effectively managing adverse winter weather conditions requires collaboration in a complex decision-making environment among inter-dependent stakeholders with varied objectives.[8] For example, airport operators are concerned about their ability to clear both the airside (i.e., runways, taxiways, de/anti-icing pads, and ramp areas) and the landside (access roads to/from the airport and parking lots) from snow and ice accumulations, and to safely operate all facilities during the winter event. Airline operators are concerned about their flight schedules, like delays and cancellations, crew time restrictions and tarmac rule compliance, and a strategy to reposition resources for recovery after the winter event. Depending on the particular airport, the de/anti-icing operations may be the responsibility of either the airport authority or airlines. Air traffic

control (ATC) is focused on expected airport arrival and departure capacities and how to manage them by means of appropriate Traffic Management Initiatives (TMI). Besides these key stakeholders, there are many others that should be included in a shared situational awareness of the approaching winter weather event as well, like the Transportation Security Administration (TSA), emergency managers, concession, facilities, and special services operators, etc.[8]

Preparatory decisions on airport staffing, readying snow removal and de/anti-icing equipment, and setting initial pavement treatment strategies are typically made 24 to 48 hours ahead of the expected onset of high-impact winter conditions. Similarly, airlines consider their flight schedules within that timeframe as well, in order to issue timely cancellations and manage rebooking of passengers, etc. Suboptimal or wrong decisions based on misleading weather forecasts can result in costly delays, diversions and last-minute cancellations, and/or a notably underutilized airport capacity.[3]

Sources of Weather-Related Information

Timely and accurate information about rapidly changing winter conditions and expected impacts is crucial for effectively managing high-impact weather events by minimizing avoidable loss and maximizing use of available airport and airline capacity. Safe and efficient flight operations require detailed information about the timing, magnitude, and spatial and temporal variation of precipitation (specifically type, intensity, and liquid water equivalent), temperature,

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Table 1. Denver traffic impacts

Date	2/20	2/21	2/22	2/23	2/24
Arrivals	618	465	567	612	573
Arr Delay (min)	6.5	15.5	28.2	16.2	4.4
Taxi In (min)	8.2	9.3	11.5	10.2	9.6
Cancelled	6	70	65	20	6
Diverted	1	8	1	8	0
Late Flights (%)	21.5	26.2	40.9	33.5	18.3
Departures	617	464	568	610	573
Dep Delay (min)	10.9	24.6	33.2	24.8	11.6
Taxi Out (min)	17.0	29.1	31.7	19.0	13.9
Cancelled	9	78	79	10	8
Late Flights (%)	24.8	36.2	48.9	43.8	23.2

wind, and ceiling and visibility in order to anticipate needed snow and ice removal activities and pavement treatments (frequency and type), and estimate manageable flight arrival and departure rates.

Here, we discuss available and emerging sources of information about weather and its translation to impacts that can support airport, airline, and air traffic managers in coping with adverse winter weather events. We highlight the February 20 to 22, 2015 winter storm impacting Denver International Airport (DEN) as a recent example to showcase various capabilities. Based on airline on-time statistics collected by the Bureau of Transportation Statistics (BTS), Table 1 indicates that there were notable impacts on air traffic during that time period, mainly in the form of cancelled flights, increased gate arrival and departure delays, increased taxi out times (due to aircraft de/anti-icing), and a few diversions. However, this winter event only produced about half the amount of snowfall depth received during the late December 2006 blizzard that shut down the Denver airport for two days, and Denver has since significantly upgraded its snow removal capabilities.[1]

Synopsis of Winter Weather Event

An arctic cold front moved into the Colorado Front Range on the afternoon of Saturday, February 21, 2015 (Figure 1). Ahead of the front, a localized area of instability resulted in a narrow band of heavy snow north and west of Denver during Friday night, resulting in four to eight inches of snow before the main snow event began the next day. As the front moved through the Denver area, surface winds shifted from northwesterly to northeasterly, forming upslope flow that increased the snowfall rate behind the front. This two-day snow event had added complexity from small-scale forcing features that produced localized areas of heavy snowfall and significant spatial variability in accumulations. Overall snowfall totals varied from eight to 12 inches in the mountains, to 10.5 inches at the Denver International Airport and 20.5 inches in Westminster, a northwestern Denver suburb that was situated under the Friday night localized heavy snow band.

Weather forecasts can be obtained from many sources, including the National Oceanic and Atmospheric Administration (NOAA) National Weather Services (NWS) and its Aviation Weather Center (AWC), a wide selection of commercial vendors, and the media as well. Various NWS products are available that are particularly useful to aviation, like the Area Forecasts (FA), Aviation Forecast Discussions (AFD), and Terminal Aerodrome Forecasts (TAF). The NWS Center Weather Service Units (CWSU) provide weather guidance specifically for Air Route Traffic Control Centers (ARTCC). In addition, the National Digital Forecast Database (NDFD) is an excellent source of fine-scale weather information. Many NWS Weather Forecast Offices (WFO) also produce customized aviation services webpages, like the Denver Area Aviation Weather Services provided by the Denver/Boulder WFO.

Outlook for Winter Weather Event

Snowfall Outlook

From mid-September through mid-May, the NWS Weather Prediction Center (WPC) issues probabilistic winter precipitation forecast products for three consecutive days extending 72 hours into the future. These products are based on a large, multi-model ensemble forecast expressing the probability of 24-hour snowfall accumulations to exceed four, eight, and 12 inches and one quarter of an inch of freezing rain. Figure 2 shows the predicted probability of snowfall to exceed four inches in 24 hours for the February 20 to 22, 2015 Denver winter weather event based on 00 UTC forecasts issued on February 20, 21, and 22, respectively. These forecasts show a consistent picture of significant snowfall accumulation potential for that weekend, especially on Sunday, February 22, 2015.

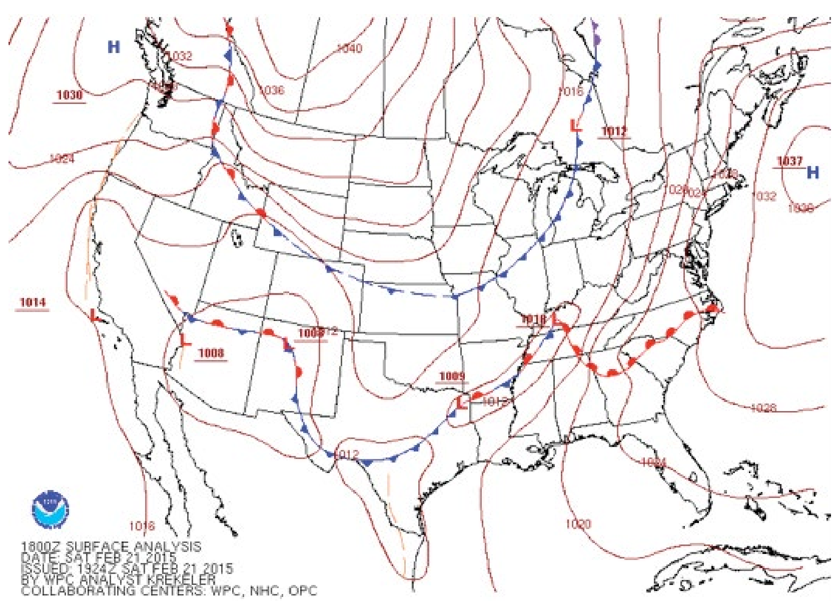

Figure 1. Synoptic weather situation for 18 UTC (11 am MST) on February 21, 2015

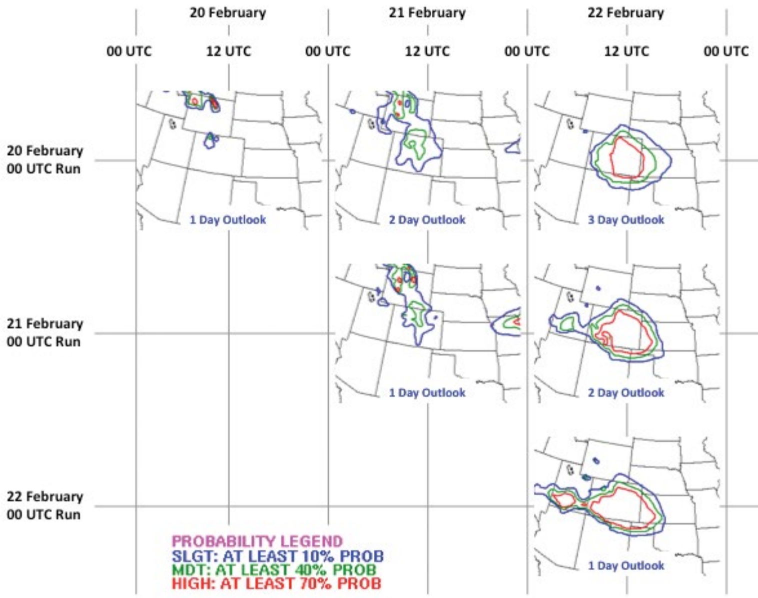

Figure 2. Probability of 24-hour snowfall accumulation exceeding 4 inches (adapted WPC products)

Operational Impact Outlook

Developed by the Collaborative Decision Making (CDM) Weather Evaluation Team (WET) with aviation industry partners, the NWS AWC has been issuing the Aviation Winter Weather Dashboard (AWWD) as a tool for depicting potential winter weather impacts across the NAS within the next 87 hours at three hour granularity. Updated four times daily, the AWWD displays the potential impact on each airport based on snowfall, freezing rain, and visibility issues predicted by the NOAA National Centers for Environmental Prediction (NCEP) Short-Range Ensemble Forecast (SREF) numerical weather prediction system. The anticipated impact is determined qualitatively, based on considering the local annual snowfall climatology and rendered through a matrix of color-coded boxes that depict nominal (green), slight (yellow), moderate (orange), and high (red) impact. This quantitative translation from a probabilistic forecast to a categorical impact takes into account relevant operational thresholds and other considerations for terminal operations. Figure 3 shows the AWWD outlook issued on Friday, February 20, 2015 for the Denver ARTCC (ZDV) with moderate operational impacts from snowfall rates exceeding 0.5 inches per hour and limited visibility expected for Sunday, although some snowfall may be experienced for most of the outlook period. The impact is considered moderate only, because Denver airport is equipped and experienced to handle significant amounts of snowfall.[1]

Airport Capacity Estimation

The Winter Weather Airport Capacity Model (WWACM),[9] developed by Metron Aviation, goes a step further by capturing precipitation rate and type (including snow liquid water equivalent), temperature and snow melting rate, de/anti-icing, and snow removal capabilities to quantify an airport's arrival and departure rates based on statistically calibrating against past records of observed winter weather conditions and associated deviations from airport capacity rates. WWACM considers the lead time to the onset of the winter weather event and accounts for weather forecast uncertainty (including bias removal) in its probabilistic estimation of airport capacity with confidence intervals as well. WWACM was calibrated for 32 U.S. airports based on data collected during the 2008–2011 winters, explaining about two-thirds of the observed variance in reduced airport departure rates.[9] Metron Aviation has been running a prototype system in real time for a dozen airports, but unfortunately Denver airport is not included in this initial selection (thus we cannot show its performance for the February 20 to 22, 2015 winter event).

Snow and Ice Removal Guidance

In early 2000, the Federal Highway Administration (FHWA) recognized the need for improved winter maintenance decision making for roadway pavement and funded the development of the Maintenance Decision Support System (MDSS)[10, 11] by the National Center for Atmospheric Research (NCAR). The MDSS utilizes a wide range of weather and pavement condition observations, output generated by several numerical weather prediction models, and statistical post-processing techniques to generate real-time, hourly updated snow and ice control guidance (e.g., treatment times, chemical choices, rates, and locations based on considering rules of best practice)[12] for user-defined roadway segments. The

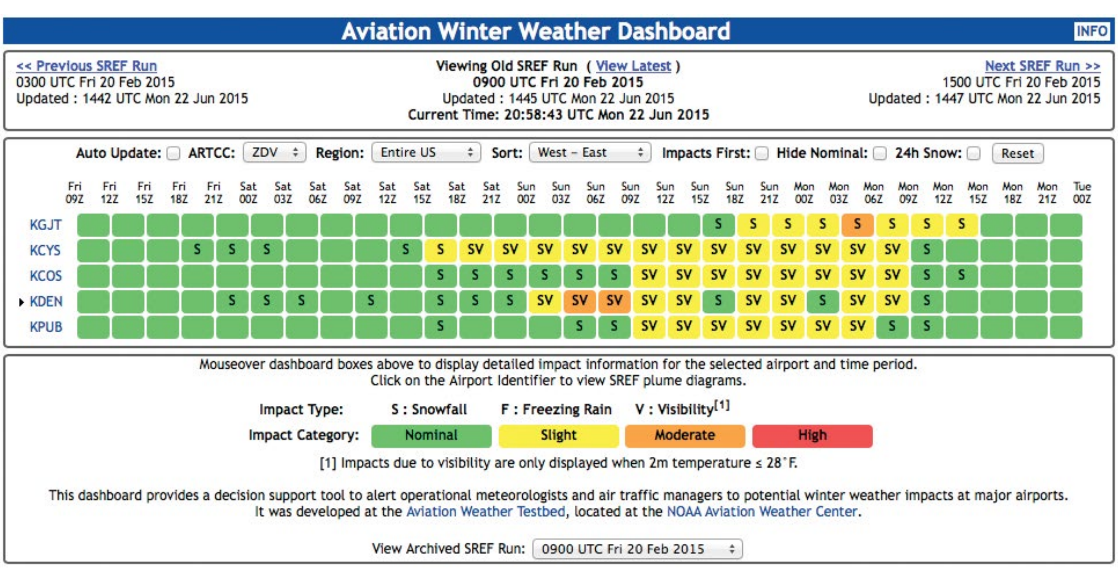

Figure 3. Aviation winter weather dashboard

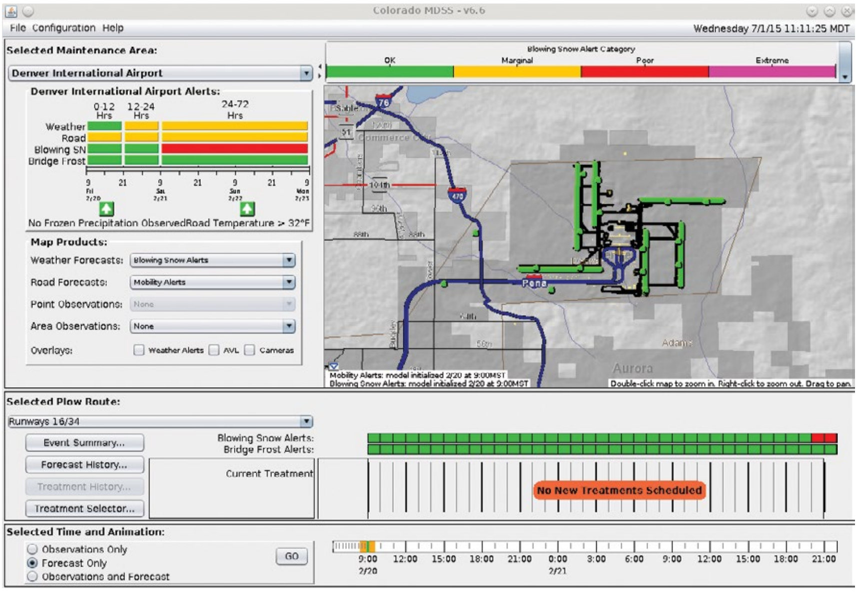

Figure 4. MDSS display for Denver airport runways and access roads

Road Weather Forecast System (RWFS) and Road Condition and Treatment Module (RCTM) are the central components of the MDSS prediction system. During the winter of 2008/2009, the MDSS was adapted for use with all six runways of the Denver airport and its main access roads. The MDSS generates a diverse set of information for each access road and runway as summarized in Table 2. The Denver airport relies heavily on this system to make more efficient strategic and tactical decisions regarding the deployment of snow removal crews during winter storms.

Figure 4 shows the Denver MDSS display at 16 UTC on February 20, 2015 with a 72-hour outlook that suggests deterioration of the runway and access road conditions during the next 12 to 24 hours (marginal conditions shown in yellow) and an alert for poor visibility and blowing snow conditions (shown in red) in the 24 to 72-hour period.

Interrogation of the display provides further details about specific runways, such as for runways 16/34 shown in Figure 5. This yields information about the precipitation type (rain, snow, or ice), the probability of these types, total new snowfall accumulation on the runway with and without snow removal treatments, the conditions on the tarmac (snow, wet, chemically wet, slush ice, or chemically iced), runway surface temperature, hourly average wind speed, and recommended runway treatments. According to this prediction, the probability of precipitation shows a 30 percent chance of snow increasing to about 60 percent and changing from rain to snow over the next six hours. Snow depth on the runway is suggested to increase to nearly 10 inches without treatment but to remain mostly minimal based on the recommended treatments leaving the runways chemically wet. Periodic plowing and application of three gallons of potassium acetate per lane mile are suggested based on the predicted surface conditions in the bottom panel.

The event was well predicted by MDSS 72 hours ahead of the event, indicating that most of the snow would fall during the evening of the 21st into the morning on the 22nd, which is what happened. However, MDSS suggested that snow would continue into Sunday evening whereas in reality most of the snow ended on Sunday afternoon. The hourly MDSS forecast updates provided refinements to the forecast throughout the event.

Monitoring During the Event

Monitoring of Changing Conditions

Along with aircraft de/anti-icing operations, the assessment of runway and taxiway surfaces, and treatment of the runway are significant disruptions to an airport's operational efficiency and causing delays. Thus, effective monitoring capabilities that provide timely and accurate information about rapidly changing wintry conditions are key to managing high-impact weather events.

Surface observations from sensors both above ground and embedded in the pavement are key for obtaining accurate and up-to-date information about the environmental and pavement conditions. In addition, radar provides frequently-updating, high-resolution, area-covering precipitation data for terminal areas and larger domains, if merged together. The Multiple-Radar Multiple-Sensor (MRMS)[13] product suite developed by the NOAA National Severe Storms Laboratory (NSSL) and the Corridor Integrated Weather System (CIWS)[14] produced by the Massachusetts Institute of Technology (MIT) Lincoln Laboratory are two commonly used radar-based nowcast products to assess the precipitation rate and type during winter weather events. Figure 6 shows the radar-based precipitation and surface wind situation for Denver airport at 00 UTC on February 22, 2015 based on a system developed by NCAR.[15] At this time, the winds are from the northeast enhancing precipitation under these upslope conditions.

De/Anti-Icing Guidance

Going beyond, and specifically supporting de/anti-icing procedures, NCAR developed a system[15] that utilizes data from a special suite of surface sensors to estimate the Liquid Water Equivalent (LWE) based on the measured snowfall rate, which is more appropriate for de/anti-icing aircraft

Table 2. MDSS guidance overview

Weather parameters (predictions out to 72 hours) • air temperature • wind speed • wind direction • relative humidity • precipitation type • precipitation rate • snow rate • snow accumulation (previous 3 hours and 72 hour total) • dew point • blowing snow potential
Runway condition parameters (out to 72 hours) • pavement temperature • snow accumulation on the pavement • water phase on pavement • chemical concentration (based on expected dilution)
Runway treatment recommendations • treatment start and end times (initial and multiple treatments) • chemical type (K Acetate) • chemical amount • user-defined treatment scenarios
Roadway condition parameters (out to 72 hours) • road temperature • snow accumulation on the road • road water phase • chemical concentration (based on expected dilution) • mobility • bridge frost potential
Roadway treatment recommendations • treatment start and end times (initial and multiple treatments) • chemical types (NaCl, MgCl2, CaCl2, CaliberTM, IceSlicerTM) • chemical amount • user-defined treatment scenarios

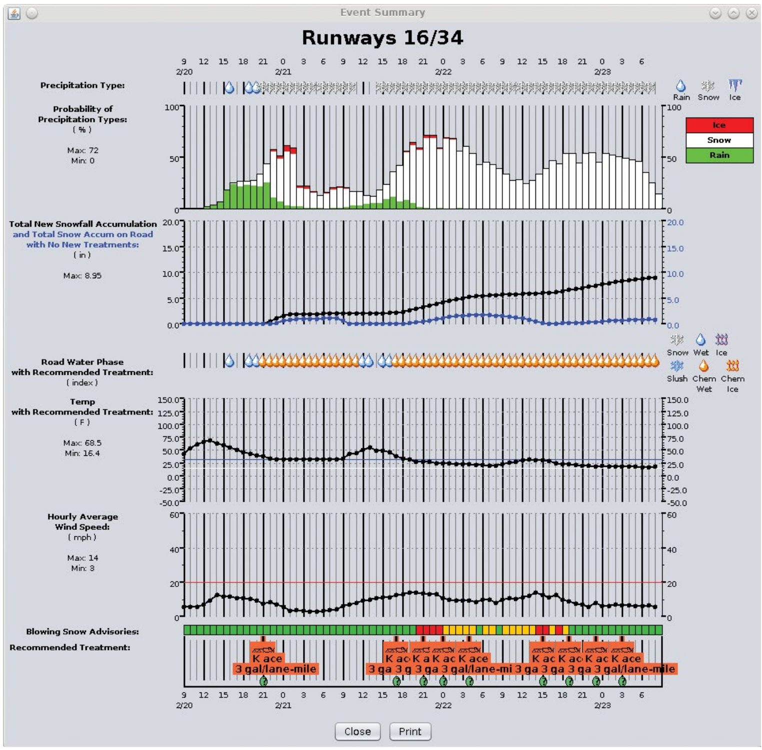

Figure 5. Runway-specific prediction of weather, pavement conditions, and suggested treatment

than guidance based on visibility.[16] The length of time the applied de/anti-icing fluid will provide protection to the aircraft (i.e., Holdover Time or HOT) depends on the time since that procedure was initiated, the LWE-derived precipitation intensity, and ambient air temperature.[17] The look-up charts utilized by pilots to assess a HOT assume that the snowfall rate (estimated based on visibility) and ambient air temperature will remain constant until takeoff, which in reality is rarely the case as snowfall rates and air temperatures can be highly variable (e.g., see Figure 6), especially at airports prone to snow squalls and lake-effect snow events. The NCAR "Checktime" real-time prototype system,[15] deployed at the Denver airport, alleviates the above concerns by directly providing a wall-clock time in the past when the de/anti-icing fluid must have been applied to avoid expiration based on the local weather conditions experienced since the procedure was applied. Checktime updates every minute, considers fluid type, applied concentration, ambient air temperature, and precipitation rates calculated by the LWE system, and accounts for wind speed. From a practical point of view, a pilot only needs to know the time when his/her plane was de/anti-iced. As long as that time remains more recent than the Checktime, their de/anti-icing fluid application is still providing adequate protection.

The Checktime display (Figure 7) shows the current observations from the LWE system in tabular form as well as the precipitation rates over the past hour so a user can monitor the conditions and discern whether precipitation trends are increasing or decreasing. The Checktime information is shown at the top left of the display with the fluid type and concentration. The difference between the current time and Checktime is shown to give the pilot an idea of how long the current estimated HOT may be lasting. The Checktime value is also shown on the graph as a vertical white line with sections to the right of that line color coded (and numerically labeled) to indicate the percentage of fluid capacity remaining. As the snowfall intensities increase, the vertical white line moves to the right side of the chart, indicating a shorter HOT and vice versa. The current time (same as situation in Figure 6) is shown on the far upper right side with time going backwards as one moves left across the graph.

Surface Friction Monitoring

The aviation community continues to struggle with runway friction reporting practices. Current friction testing measurements on runways lack a uniform standard. Moreover, pilot braking action reports provide only a subjective assessment of braking conditions and can vary significantly depending on a pilot's level of experience and the type of aircraft in use. The consensus of many assessments of runway braking action is that there is no exact relationship between the coefficient of friction and an aircraft's actual stopping capability, and that reports of braking action are qualitative at best and can be transitory in nature.[18, 19] In response to the National Transportation Safety Board's (NTSB) urging,[5] the aviation industry has been developing and demonstrating technologies to provide timely, accurate, and aircraft-independent information that conveys an airplane's braking ability required and/or available to slow or stop the airplane during the landing roll by automatically retrieving and analyzing data collected by aircraft sensors and on-board flight-control computers. Testing of innovative landing safety technologies is underway by Airbus and Boeing, and smaller companies like Aviation Safety Technologies (AST) and Kongsberg

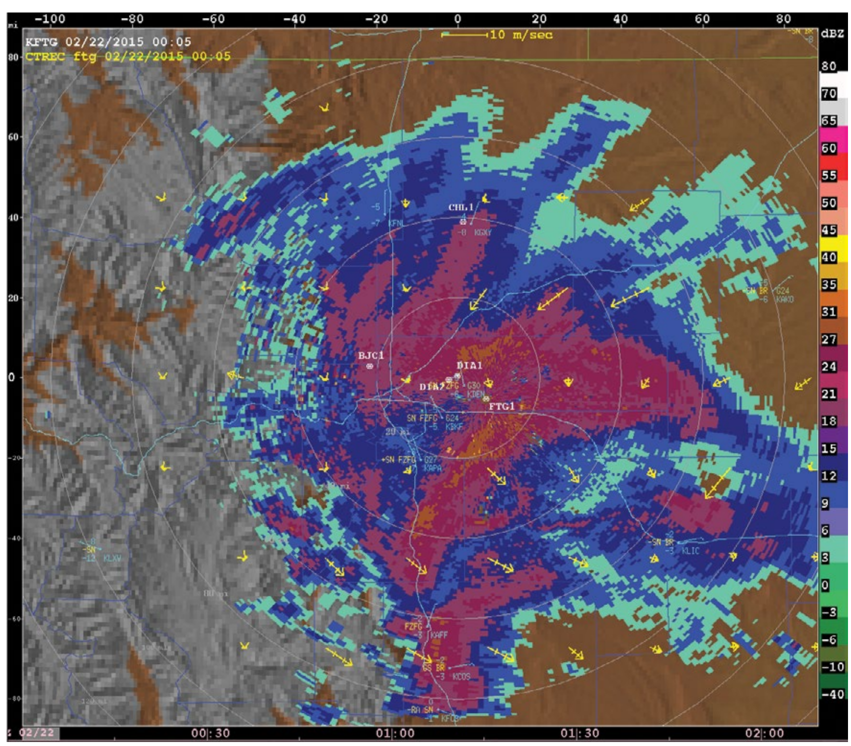

Figure 6. Radar-based monitoring of local weather conditions

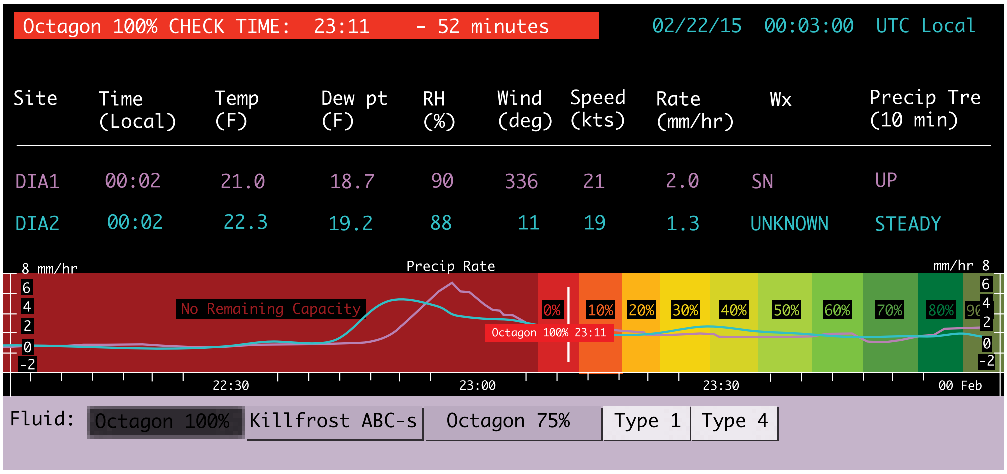

Figure 7. Checktime de/anti-icing guidance

Aeronautical, in cooperation with several airline partners; it shows promise to enhance both safety and efficiency of operations during winter weather.[20, 21, 22, 23]

A Vision for the Future

The capabilities discussed in this article are based on stand-alone systems requiring a planner and decision-maker to mentally integrate information obtained from multiple systems and displays. However, decisions are increasingly difficult to make under the time pressure exerted by high-impact weather situations and associated prediction uncertainties.

A rapidly updating and comprehensive situational awareness is needed (and to be shared among all airport stakeholders) that requires timely incorporation of information from all available sensors above ground and embedded in pavement, as well as the potential inclusion of sensors on vehicles around the airport grounds and landing aircraft to form a large network of temporally and spatially dense observations for providing current and predicted guidance to operators with a sense of how much confidence they may place on the anticipated outcome.

Looking to the future, increasing connectivity, data gathering and sharing, and data mining intelligence will provide opportunities for operators to make use of smart decision support tools that can be tailored to their needs and provide possible outcome scenarios with associated likelihood, calibrated against past experience with similar situations.

Aspects of such a vision are already being explored by the FHWA through its Road Weather Management Program[24] using connected vehicle technologies that are expected to "dramatically expand the amount of data that can be used to diagnose, 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."[25]

It's time to begin exploring research and development activities that focus on the integration of multiple existing and emerging capabilities such as those highlighted herein to further optimize airport ground and airside operations.

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Winter Weather Websites and Prototypes

The websites shown below are listed in the order the products were mentioned in the article. If no real-time product website is publically available, please contact the developers for further details.

Area Forecasts (FA)
http://www.aviationweather.gov/areafcst
Note that the FA is being phased out by the NWS.

Aviation Forecast Discussions (AFD)
http://www.aviationweather.gov/fcstdisc

Terminal Aerodrome Forecasts (TAF)
http://www.aviationweather.gov/taf

Center Weather Service Units (CWSU)
http://www.aviationweather.gov/cwamis

National Digital Forecast Database (NDFD)
http://digital.weather.gov

Denver Area Aviation Weather Services
http://www.weather.gov/bou/aviation

Weather Prediction Center (WPC) three-day probabilistic winter weather outlook
http://www.wpc.ncep.noaa.gov/wwd/winter_wx.shtml

Aviation Winter Weather Dashboard (AWWD)
http://www.aviationweather.gov/decisionsupport/winter dashboard

Winter Weather Airport Capacity Model (WWACM)
Contact Metron Aviation for details

Maintenance Decision Support System (MDSS)
Contact the NCAR Research Applications Laboratory for details

Multiple-Radar Multiple-Sensor (MRMS)
http://mrms.ou.edu

Corridor Integrated Weather System (CIWS)
https://ciws.wx.ll.mit.edu

CheckTime
Contact the NCAR Research Applications Laboratory for details