P 1.14 EVALUATION OF EXTINCTION COEFFICIENT ALGORITHMS FOR OPTIMIZING REPORTED VISIBILITY CONDITIONS FOR AIR TRAFFIC CONTROL APPLICATIONS

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1. INTRODUCTION

This paper examines the potential of using previously measured extinction coefficients (σ or excos) over different time intervals for projecting visibility conditions over future short time intervals for operational purposes. The focus is on evaluating the prediction of visibility conditions during time intervals ranging from one to five mins with the two-min future time considered to be most applicable to aircraft on final approach. This two-min forward time is considered representative of the time it takes for a modern aircraft to reach the touchdown point on the runway from the outer marker which ranges from around 4- to 7-nm from the runway threshold. Two min is also taken as the shortest time prior to landing that a pilot would expect to receive a visibility report from a controller. Algorithms for forecasting visibilities out to five-min or longer times from the current time are desirable for use in coasting visibility sensor readings in the event of a visibility sensor outage. The cost of such an event during poor visibility conditions is possible loss of runway operational service to aircraft on final approach.

Background - Visibility sensor (VS) data, covering many types of natural weather conditions that result in decreased visibilities, i.e., Runway Visibility Range (RVR) events, are used for the analyses. Such events are defined as any time when RVR is less than 6,500-ft (US) or 1,600-m (international). The most common causes are fog and snow. In the US, the 3 categories (CAT) of RVR are: CAT I for 2,400 ≤ RVR ≤ 6,500-ft; CAT II for 1,200 ≤ RVR < 2,400-ft; and CAT III for RVR < 1,200-ft. Thirty-nine such events, associated with daytime conditions, from Dec 2007 - July 2008 were evaluated. Most of the events experienced each RVR category at different times. A listing of the events is given in Table 1. The entries indicate the event date; the number of mins the VS was reporting CAT I, II and III conditions; the approximate maximum σ on the event date; the maximum RVR category attained on the event day 'Max RVR CAT'; and the prevailing weather conditions according to the official surface or METAR reports.

RVR values reported to controllers are computed products that depend on measurements of σ obtained from VSs on active runways, runway light settings and background luminance. For the purposes of this study, Koschmeider's Law was used to compute RVR, i.e.,

$$V = 9842.5\ \sigma^{-1} \qquad (1)$$

where V is the visibility in ft and σ is in km^{-1}. This corresponds to ranges of σ from about 1.5 - 4.1 km^{-1} for CAT I conditions; 4.1 - 8.2 km^{-1} for CAT II; and over 8.2 km^{-1} for CAT III (Seliga et al., 2006). CAT 0 is used to describe σ less than about 1.5 km^{-1}. Eq. 1 represents a 'worst case' calculation of RVR, compared to RVR calculations under most nighttime runway operations.

Data from a VS named 'NG VS03' or 'NGRVR VS03' at the Otis Weather Test Facility (WTF) located at the Otis Air National Guard Base near Falmouth, MA on Cape Cod were used. Data of 1-min running averages, received at 10-s intervals form the basis of the analyses.

Algorithms for projecting or nowcasting visibility sensor measurements 1-5 min into the future are compared and evaluated by tabulating the percent of time the projected and actual VS measurements yield the same RVR category (0, I, II or III), the percent of time the predicted RVR category is one or more categories less than the actual and when the predicted RVR category was greater than the actual. The results are given in both tabular and plotted formats. The nowcasts are based on: last value data coast; linear regression using 3-min, 5-min, and 9-min previous time intervals; and backward (BW) averaging over 2-min, 3-min, 4-min, and 5-min previous time intervals. For safety purposes, in the linear regression method, σ was coasted if the slopes were negative.

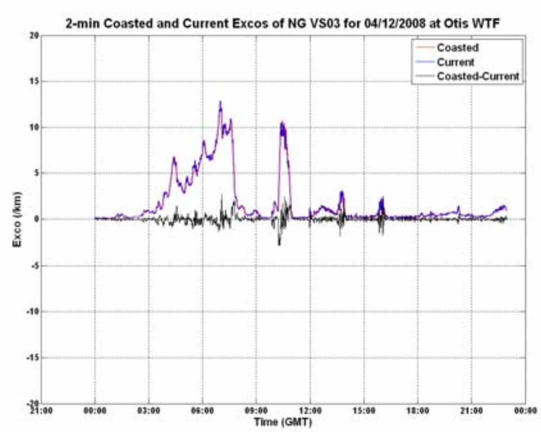

Fig. 1 – Sample Time Series Plot Illustrating 2-min Data Coast.

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A sample time history plot, illustrating 2-min data coast for a typical event, is shown in Fig. 1. The plot compares the 2-min coasted σ shown in the red curve and actual σ shown in the blue curve. The black curve in Fig. 1 is the error defined as the difference between the coasted and actual readings. Negative errors may sometimes result in predicted RVR being less than the actual RVR.

Table 1 - Low-Visibility Events at Otis WTF from December 2007-July 2008.

Date	Mins CAT I	Mins CAT II	Mins CATIII	Max σ	Max RVR CAT	Weather
12/13/07	231.00	89.67	72.33	10	III	Snow, Sleet, Mist, Freezing Fog
12/16/07	103.83	127.33	127.50	33	III	Snow, Rain (moderate at times), Drizzle, Freezing Rain, Freezing Drizzle, Mist, Freezing Fog
12/20/07	73.00	62.17	44.00	11	III	Rain, Snow, Drizzle, Mist
01/09/08	22.67	27.83	17.67	9	III	Mist, Fog, Brief Rain
01/27/08	236.33	72.33	72.50	21	III	Snow, Mist, Freezing Fog
01/28/08	122.33	138.50	94.67	21	III	Snow, Mist, Freezing Fog, Blowing Snow
02/06/08	251.17	276.83	195.83	26	III	Mist, Fog, Rain
02/13/08	103.00	0.50	0.00	4	II	Snow, Mist, Rain. Rain heavy towards end of day.
02/14/08	23.17	0.00	0.00	4	II	Mist, Rain
02/27/08	159.00	111.00	100.00	13	III	Mist, Fog, Rain. Rain moderate-heavy at times early in day.
03/07/08	6.00	3.67	2.17	30	III	Fog
03/08/08	260.00	187.00	186.17	12	III	Mist, Fog, Drizzle, Rain. Rain moderate-heavy at times late in day.
03/12/08	49.33	2.00	0.83	14	III	Mist, Rain Showers
03/20/08	129.50	171.50	114.83	12.5	III	Fog, Mist, Rain, Drizzle
04/02/08	53.00	155.00	25.83	8.5	III	Mist; rain at start of day
04/04/08	181.33	93.83	71.83	12	III	Mist, Fog, Rain (moderate at times).
04/05/08	52.00	80.50	0.00	8	III	Mist, Fog, Drizzle, Rain.
04/10/08	91.17	21.00	0.00	8	III	Mist, Fog, Drizzle, Rain.
04/12/08	116.50	123.83	112.83	12	III	Mist, Fog, Drizzle, Rain (moderate at times). Several Thunderstorms.
04/13/08	76.67	55.33	12.00	13	III	Mist, Fog, Brief periods of Rain
04/22/08	127.17	78.67	54.00	15	III	Mist, Fog
04/23/08	23.83	49.83	30.17	22	III	Mist, Fog
05/04/08	129.00	51.67	35.00	12	III	Mist, Fog, Rain, Drizzle
05/06/08	9.67	30.83	22.17	19	III	Ground Fog based on Excos
06/01/08	104.33	79.33	79.50	13	III	Fog, Mist, Drizzle; Brief light-moderate rain periods early in day
06/04/08	140.17	0.00	0.00	3	I	Mist, Fog, Drizzle, Rain (moderate at times).
06/05/08	315.83	14.83	10.00	18	III	Mist, Fog with brief periods of Rain and Drizzle
06/06/08	71.33	8.17	5.67	10	III	Mist, Fog with brief periods of Rain and Drizzle
06/07/08	214.50	52.83	0.00	7	II	Mist, Fog
06/11/08	263.50	0.00	0.00	3	I	Haze, Mist
06/20/08	67.00	47.83	44.50	39	III	Mist; Ground Fog based on excos
06/22/08	36.83	6.67	2.33	16	III	Mist; Ground Fog based on excos
06/24/08	53.33	90.83	62.50	10	III	Mist, Fog, Haze; Light-Moderate Rain during Thunderstorms
06/27/08	68.67	56.33	43.83	11	III	Mist, Haze, Occasional Light-Moderate Rain
06/29/08	84.67	219.50	26.33	20	III	Mist, Fog, Haze; Thundershower with Light Rain late in day.
07/01/08	34.67	24.50	18.00	24	III	Mist, Fog, Haze
07/09/08	104.83	17.50	0.00	5	II	Mist, Haze
07/14/08	188.33	50.67	35.33	8.5	III	Mist, Fog; Brief Rain, including heavy Rain late in day
07/18/08	54.17	30.67	30.17	51	III	Mist; Ground Fog based on excos

2. RESULTS

Event Plots - Fig. 2 shows the percent of times the predicted RVR category was less than the actual for nowcasts of 1-min, 2-min, 3-min, 4-min, 5-min for data coast (upper left), and linear regression using 3-min, 5-min and 9-min regression times (upper right, lower left and lower right, respectively) with data coast used instead if the regression slope was negative. In general, the regression-based percentages were equal or slightly less than those for data coast, depending on the event and the nowcasting time. Fig. 3 shows the percentages of times the predicted RVR category was less than the actual for the same set of nowcast time intervals for data coast (upper left), and coasting of the averages using 2-min, 3-min and 5-min BW time intervals (upper right, lower left and lower right, respectively). In general these percentages were comparable with data coast for the 2-min BW averaging time with the percentages increasing slightly with increasing averaging times. For both the regression and BW averaging methods, the percentages tend to increase somewhat with increasing nowcasting times.

Fig. 4 shows the percentages of times the predicted RVR category was at least two categories less than the actual for nowcasts of 1-min, 2-min, 3-min, 4-min, 5-min for data coast (upper left), and linear regression using 3-min, 5-min and 9-min regression times (upper right, lower left and lower right, respectively) with data coast used instead if the regression slope was negative. In general, these percentages were equal or slightly less than those for data coast, particularly with 3-min regression times. There is a slight overall increase in percentages with increasing regression times. Fig. 5 shows the percent of times the predicted RVR category was at least two less than the actual for nowcasts of 1-min, 2-min, 3-min, 4-min, 5-min for data coast (upper left), and BW averages using 2-min, 3-min and 5-min time intervals (upper right, lower left and lower right, respectively). In general these percentages were comparable with data coast for the 2-min BW averaging time while increasing very slightly with increasing averaging times. Again, the percentages tend to increase with increasing nowcasting time with the rate of increase varying considerably from event to events.

Fig. 6 shows the percent of times the predicted RVR category was greater than the actual for nowcasts of 1-min, 2-min, 3-min, 4-min, 5-min for data coast (upper left), and linear regression using 3-min, 5-min and 9-min regression times (upper right, lower left and lower right, respectively) with data coast used instead if the regression slope was negative. In general, the regression-based percentages were considerably more than that for data coast, with the percentage often increasing slightly with increasing regression times. Fig. 7 shows the percentages of times the predicted RVR category was greater than the actual for nowcasts of 1-min, 2-min, 3-min, 4-min, 5-min for data coast (upper left), and BW averages using 2-min, 3-min and 5-min time intervals (upper right, lower left and lower right, respectively). In general these percentages were comparable with data coast for the 2-min BW averaging time while often increasing slightly with increasing averaging times.

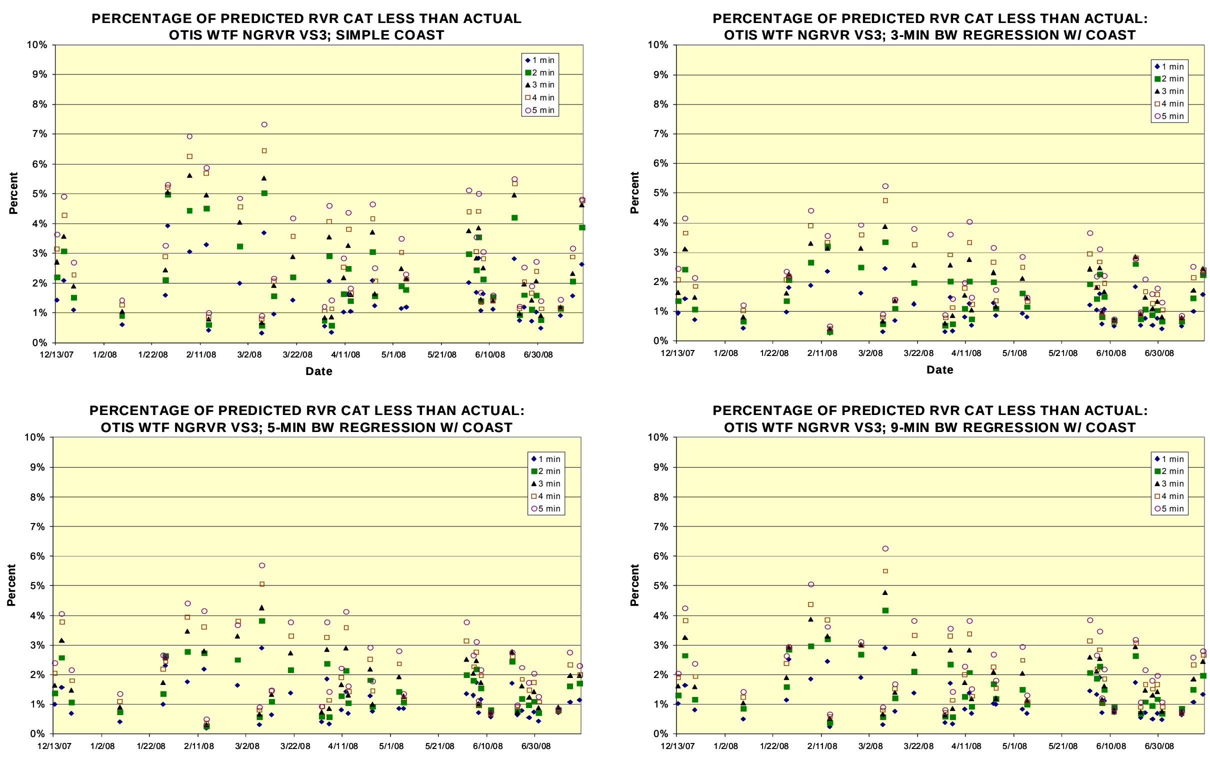

Fig. 2 – Predicted RVR Category less than Actual: Comparison of Data Coast with 3-min, 5-min and 9-min Regression with Coast if Regression Slope is Negative.

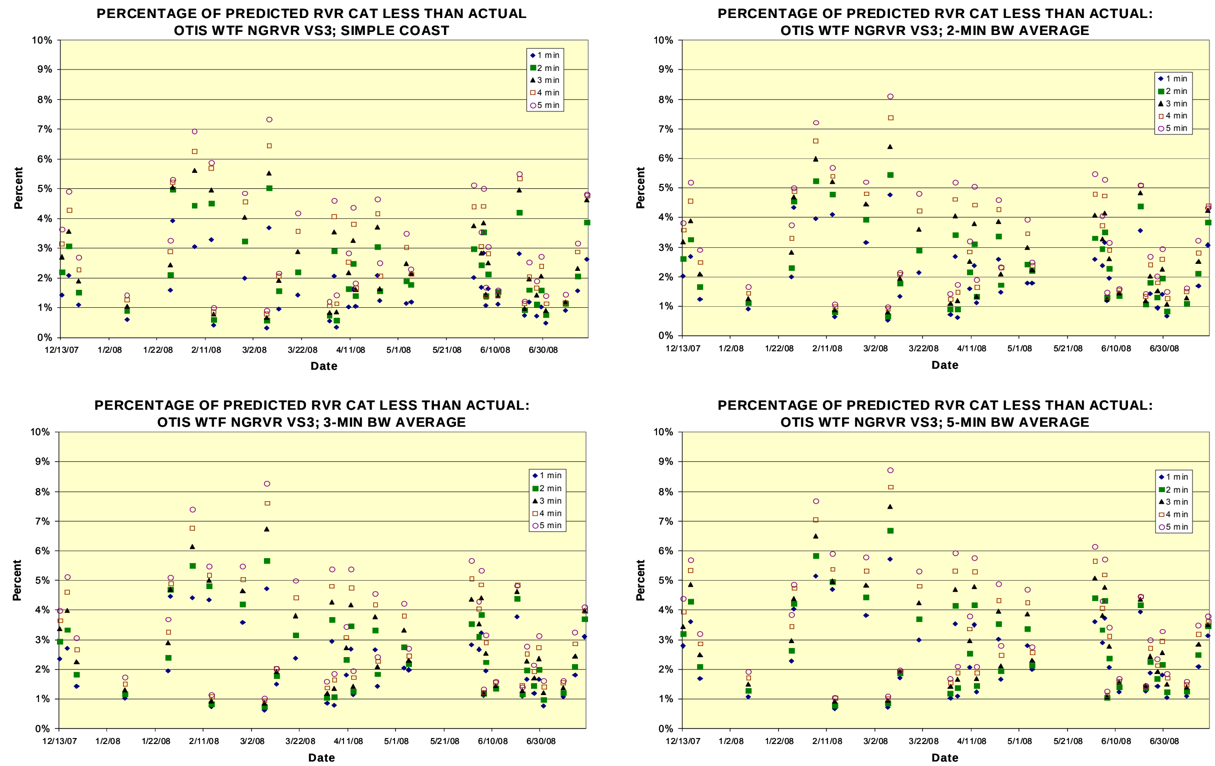

Fig. 3 – Predicted RVR Category less than Actual: Comparison of Simple Coast with 2-min, 3-min and 5-min BW Averaging.

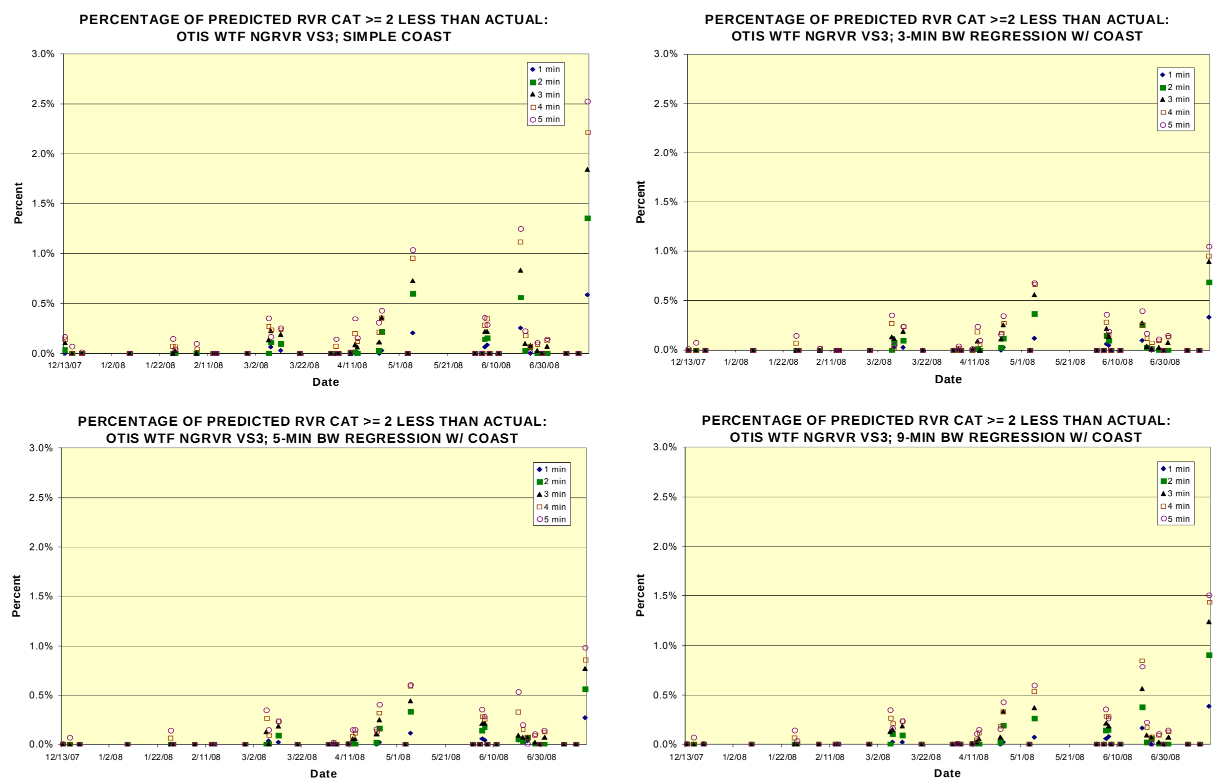

Fig. 4 – Predicted RVR Category at least two less than Actual: Comparison of Simple Coast with 3-min, 5-min and 9-min Regression with Coast if Regression Slope is Negative.

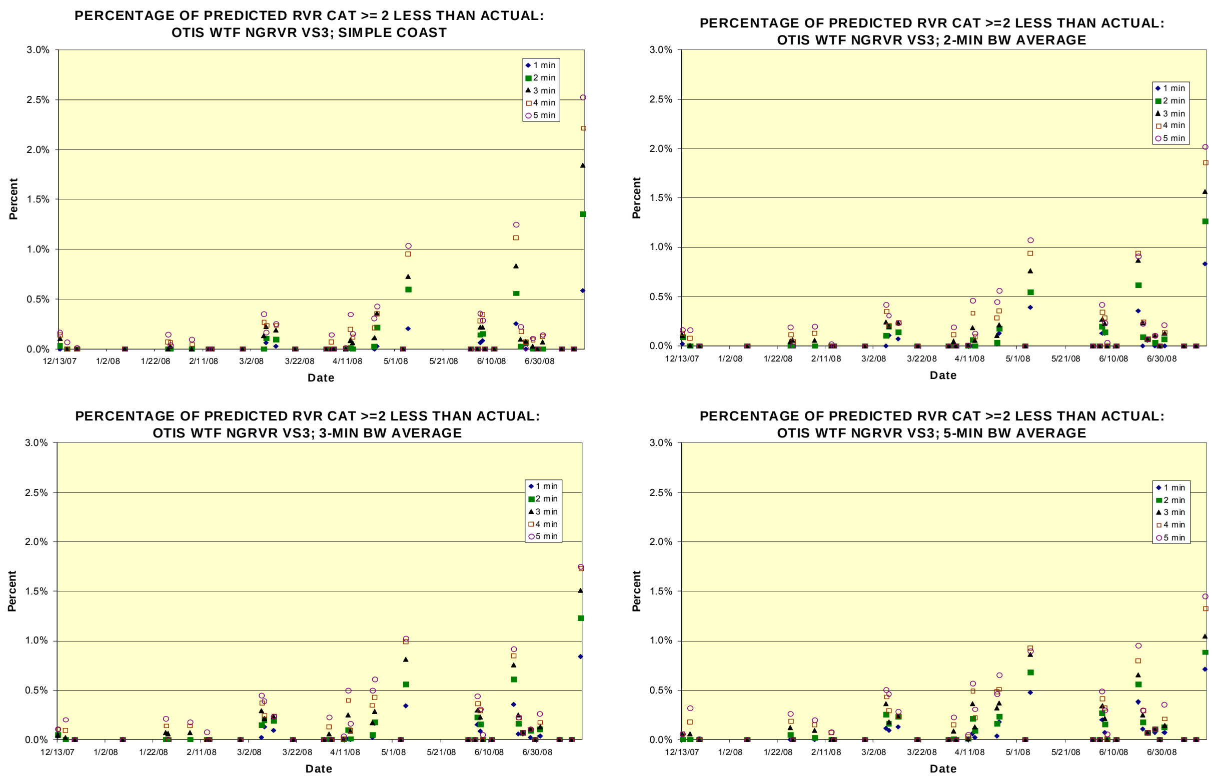

Fig. 5 – Predicted RVR Category at least two less than Actual: Comparison of Simple Coast with 2-min, 3-min and 5-min BW Averaging

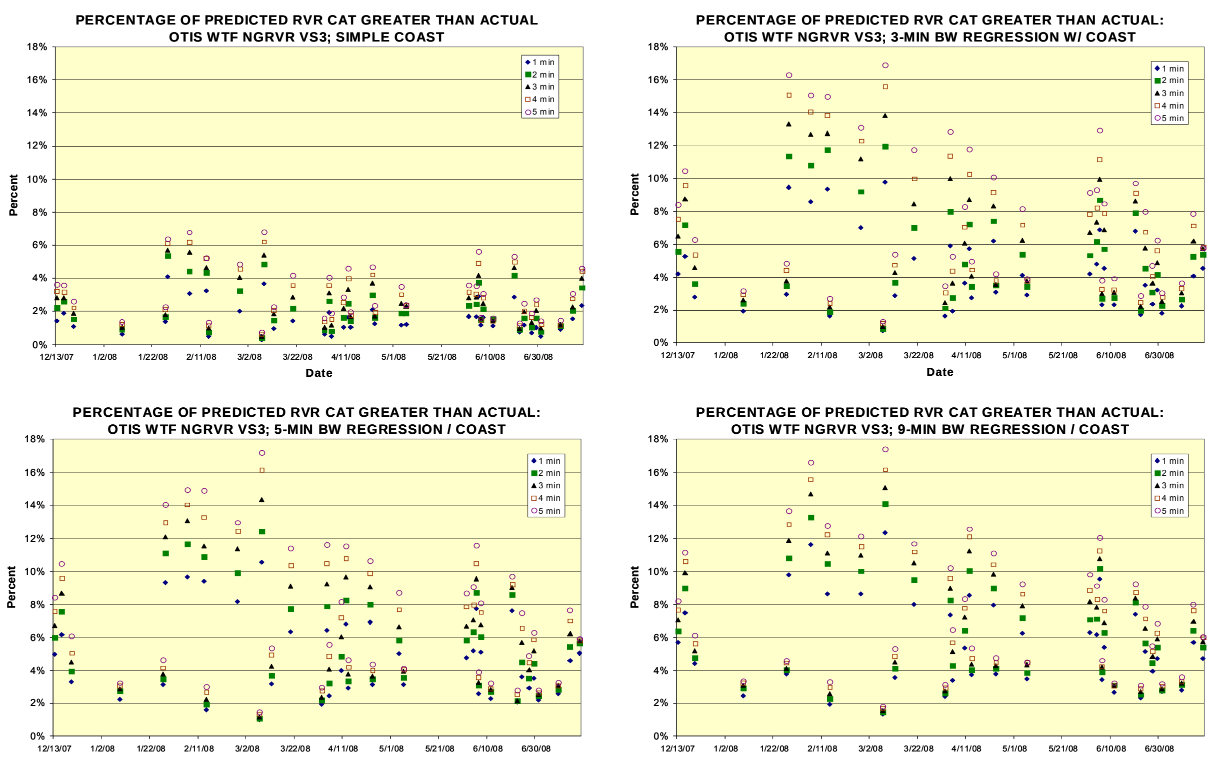

Fig. 6 – Predicted RVR Category greater than Actual: Comparison of Simple Coast with 3-min, 5-min and 9-min Regression with Coast if Regression Slope is Negative

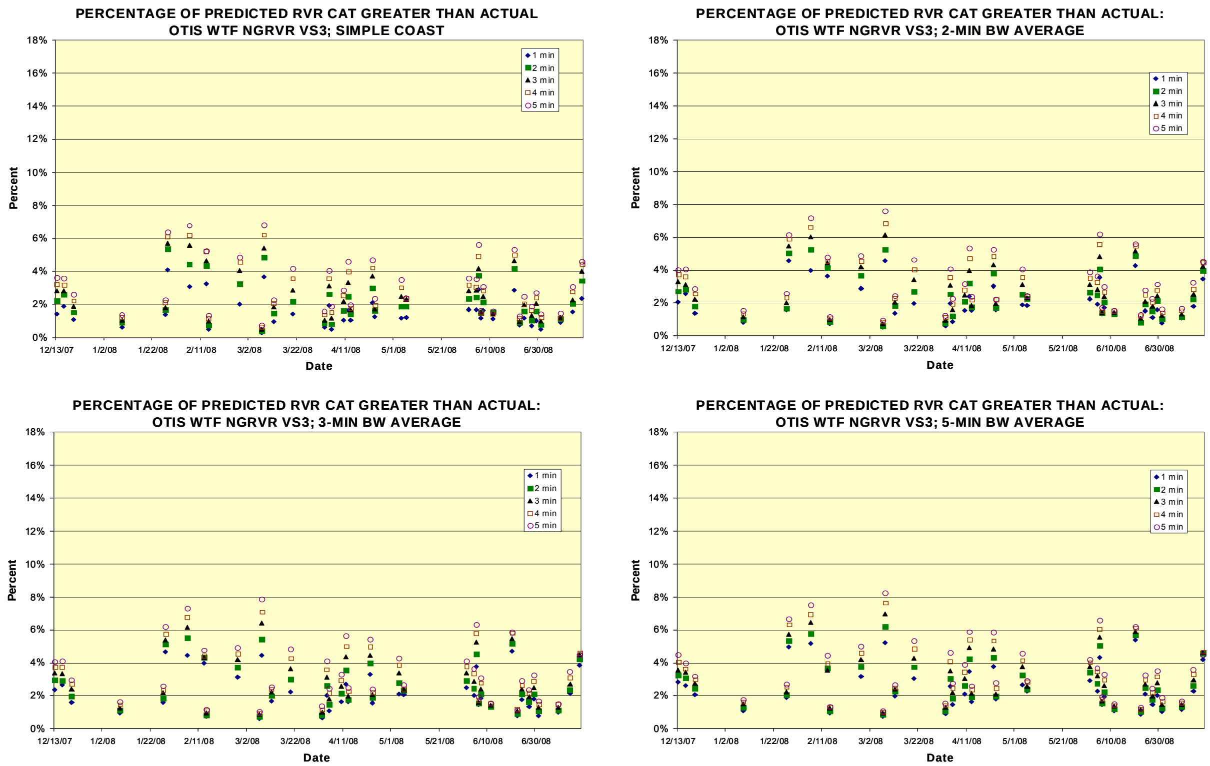

Fig. 7 – Predicted RVR Category greater than Actual: Comparison of Simple Coast with 2-min, 3-min and 5-min BW Averaging

Two-min Nowcasts – This section compares two-min nowcasts with actual values in order to assess different RVR reports to pilots, assuming the pilot receives the latest controller report two-min prior to touchdown. Fig. 8 shows the percentages of predicted RVR category being less than actual for data coast and 3-min, 5-min and 9-min regressions with data coasts used if the regression slopes were negative. The regression-based nowcasting percentages are generally less than data coast-based nowcasts by amounts varying considerably event by event. For most events, the percentage increases with increasing regression times. There are, however, a few events such as Dec. 13, 2007 and July 1, 2008 where the lowest percentages are at the 9-min regression time instead of 3-min. Fig. 9 shows the percentages of predicted RVR category less than actual for data coast and predictions based on 2-min, 3-min and 5-min BW averages. The percentages for the BW average-based nowcasts are comparable with data coast-based nowcasts with the BW average-based nowcast percentages somewhat higher than coast-based nowcast percentages for most events. For most events, the percentages increase with increasing BW averaging times.

Fig. 10 shows the percentages when the predicted RVR category was at least two less than actual for data coast and 3-min, 5-min and 9-min regressions with data coasts if the regression slopes were negative. The percentages for the regression-based nowcasts are zero for many events for all three regression time intervals and, for other events, are generally lower than data coast-based nowcasts by amounts varying considerably event-by event. The percentages from the regression technique were below 1% for all events. Fig. 11 shows the percentages for data coast and 2-min, 3-min and 5-min BW averages. The percentages for the BW average-based nowcasts are comparable with data coast-based nowcasts with the BW average-based nowcast percentages somewhat higher than coast-based nowcast percentages for most events. As in Fig. 10, the percentages were zero for many events for at least one averaging interval, and often, for all averaging intervals.

Fig. 12 shows the percentages of predicted RVR category greater than actual for data coast and 3-min, 5-min and 9-min regressions with data coasts if the regression slopes were negative. The percentages for the regression-based nowcasts are also generally higher than data coast-based nowcasts by amounts varying considerably event-by event; this result is expected, since times with negative regression slopes apply coasted values in place of regression values in order to force reporting of conservative (more safe) values when visibility would normally be improving. The percentages increase with the length of the regression interval for most events. Some events, however, such as January 28, 2008 and February 14, 2008 had the lowest percentages at the 9-min regression interval instead of the 3-min interval. Fig. 13 shows the percentages for data coast and 2-min, 3-min and 5-min BW averages. The percentages for the BW average-based nowcasts are somewhat higher than data coast-based nowcasts for most events. The percentages increase with the length of the averaging interval for most events with the spread tighter than from the regression method. One event, namely, the January 28, 2008 event had the lowest percentages at the 5-min averaging interval instead of the 2-min interval.

The general features of the results support use of a 3-min regression with coasting of the value when the regression slope is negative as the best nowcast for pilot reports of RVR by controllers under the assumed reporting scenario. Such reports would reduce times when RVR categories are less than actual by as much as a factor of two compared to current practice of using the latest value of RVR for controller reports to pilots. Application of the algorithm would increase false alarms (RVR CAT higher than actual), but this may be preferable operationally.

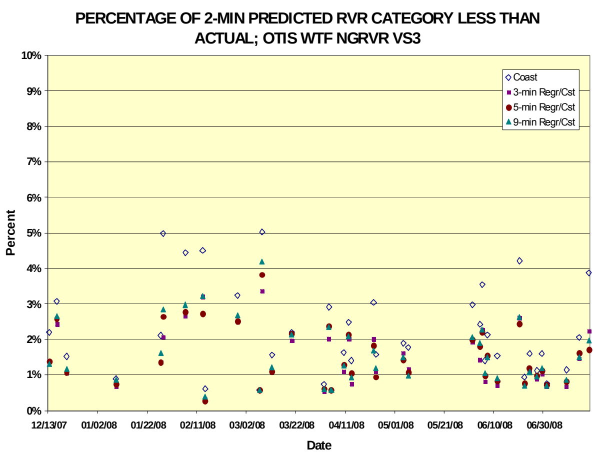

Fig. 8 – Predicted RVR Category less than Actual for 2-min Nowcasts: Comparing Data Coast and Regressions with Coast if Regression Slope is Negative.

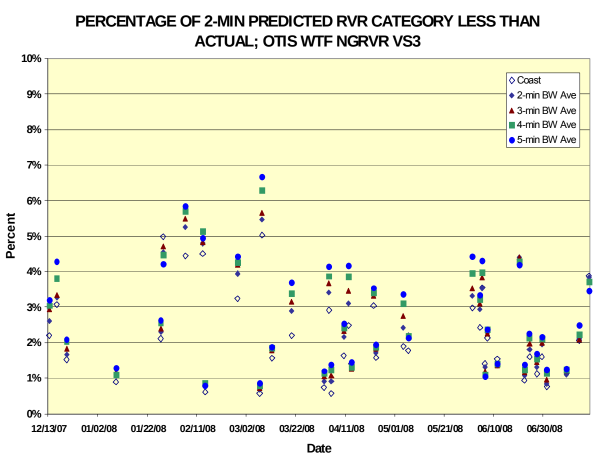

Fig. 9 - Predicted RVR Category less than Actual for 2-min Nowcasts: Comparing Data Coast and BW Averaging.

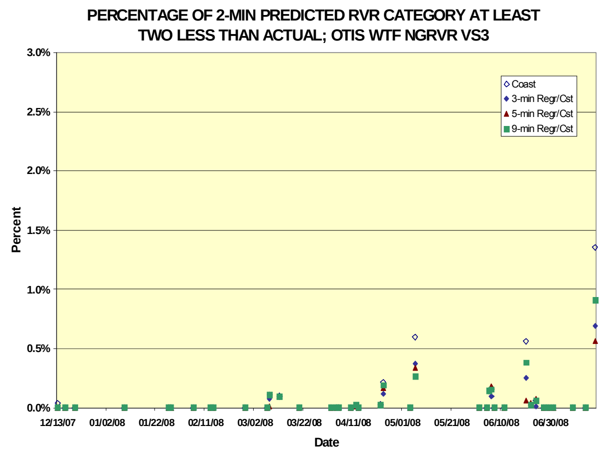

Fig. 10 – Percentages for 2-min Nowcasts where the predicted category was at least two less than actual: Comparing Data Coast and Regressions with Coast if Regression Slope is Negative.

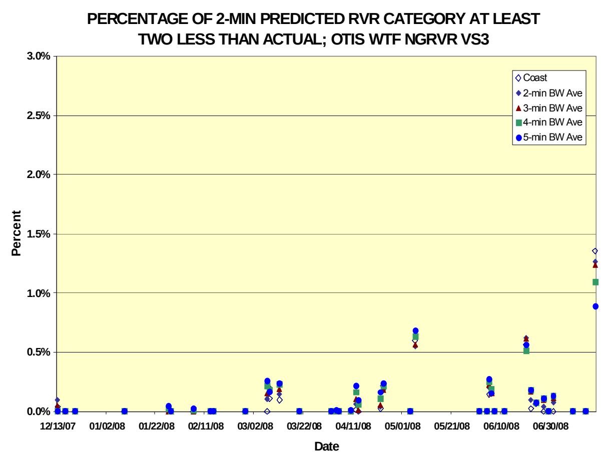

Fig. 11 – Percentages for 2-min Nowcasts where the predicted category was at least two less than actual: Comparing Data Coast and BW Averaging.

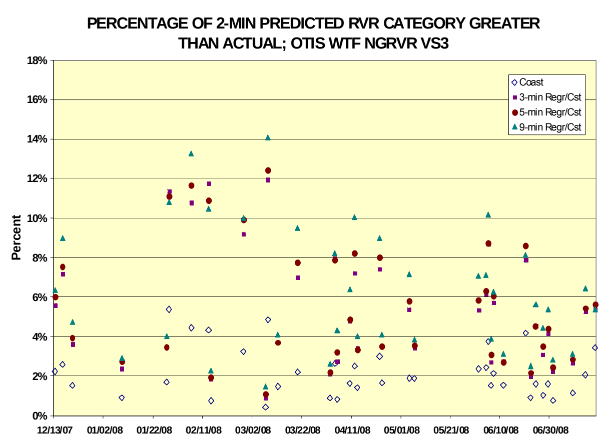

Fig. 12 – Predicted RVR Category greater than Actual for 2-min Nowcasts: Comparing Data Coast and Regressions with Coast if Regression Slope is Negative.

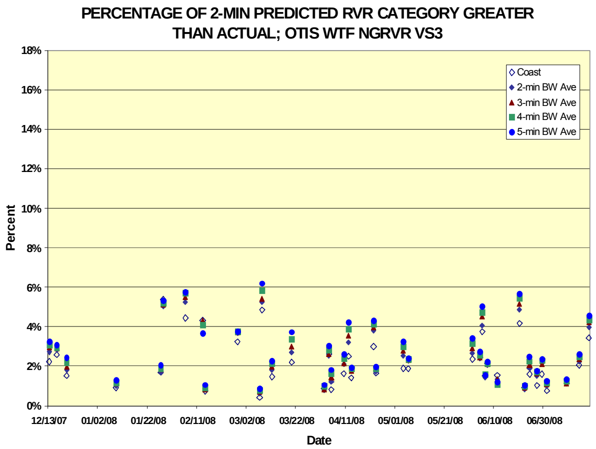

Fig. 13 - Predicted RVR Category greater than Actual for 2-min Nowcasts: Comparing Data Coast and BW Averaging.

Overall Statistics – Fig. 14 shows the percentages of predicted RVR category less than actual averaged for all 39 events. The results apply to nowcasts of 1-5 min from current time. The chart confirms the above finding that linear regressions with data coasted if the regression slope is negative yielded the lowest percentages for all nowcasting times. There is also a very slight increase in percentages with increasing regression times. The percentages for data coast are somewhat higher than the regression with coast algorithm. For all nowcasting algorithms used, the percentage increases with increasing nowcasting times. Fig. 15 shows the maximum percentages of all 39 events. The results are similar except that the maximum percentages are generally 2-3 times higher than the average.

Fig. 16 shows the average percentages of predicted RVR category at least two less than actual for all 39 events using all algorithms considered. Again the regression with data coast if the regression slope is negative yielded the lowest percentages, followed closely by data coast and backward averaging. The results for the maximum percentages shown in Fig. 17 are similar with the percentages approaching an order of magnitude higher that of the average percentages.

Fig. 18 shows the percentages of predicted RVR category greater than actual averaged for all 39 events. The chart confirms the above finding that linear regressions with data coasted if the regression slope is negative yielded the highest percentages for all nowcasting times ranging from 1-5 min. There is also little change in percentages with increasing regression times. The percentages for data coast turns out to be the lowest of all algorithms considered, followed closely by backward averaging. For all nowcasting algorithms used, the percentage increases with increasing nowcasting times. Fig. 19 shows the maximum percentages of all 39 events. The results are similar except that the maximum percentages are generally 2-3 times higher than the average percentages.

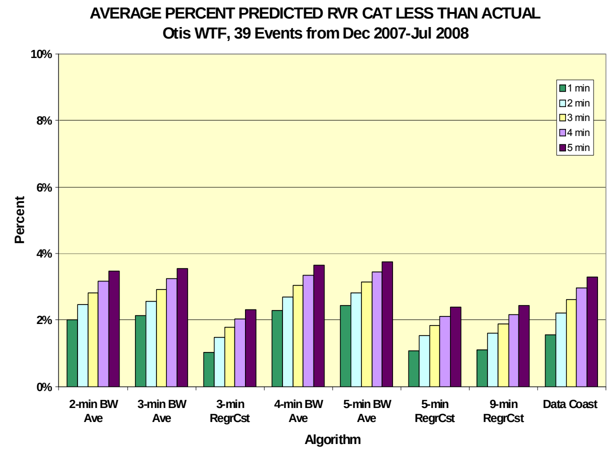

Fig. 14 – Average Percentages of Predicted RVR Category Less than Actual.

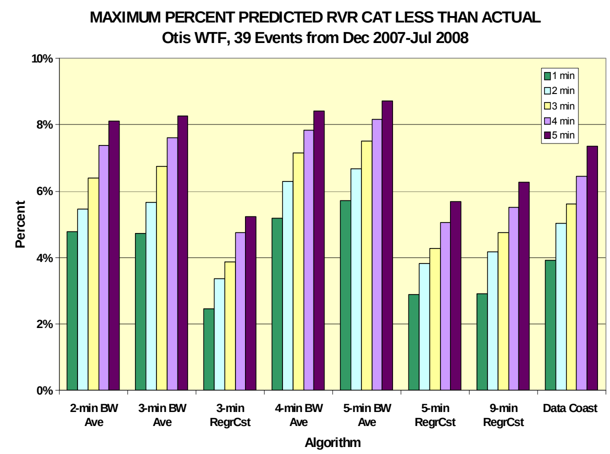

Fig. 15 – Maximum Percentages of Predicted RVR Category Less than Actual.

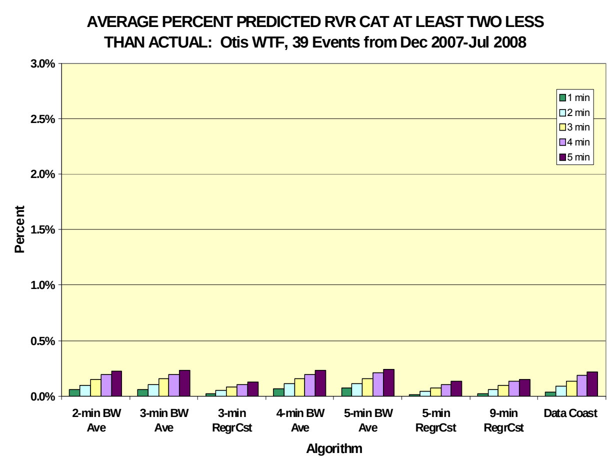

Fig. 16 – Average Percentages at Least Two Categories Less than Actual.

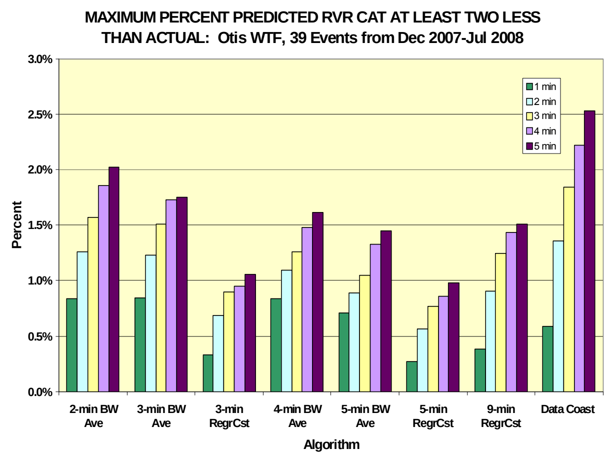

Fig. 17 – Maximum Percentages at Least Two Categories Less than Actual.

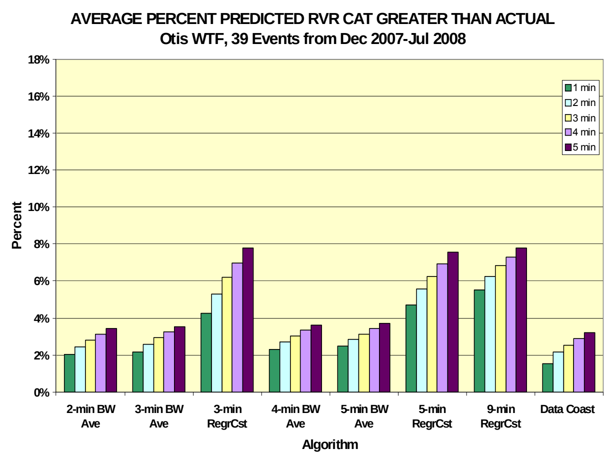

Fig. 18 – Average Percentages Predicted RVR Category Greater than Actual.

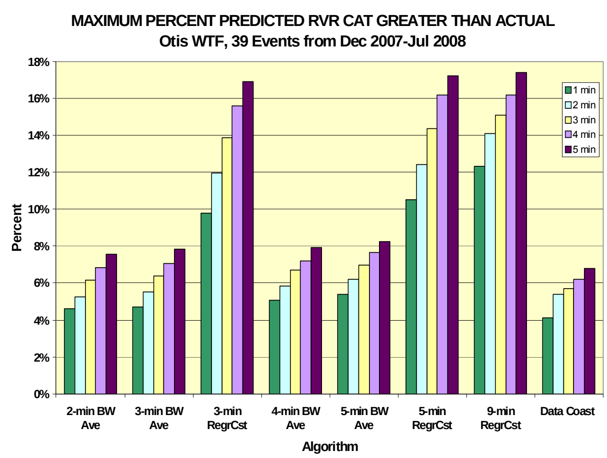

Fig. 19– Maximum Percentages Predicted RVR Category Greater than Actual.

3. SUMMARY

This paper examined the potential of utilizing previously measured σ over different time intervals for projecting RVR over future time intervals for operational purposes. RVR categories were predicted for times ranging from 1-5 min from the current time. Another consideration dealt with the 2-min future time, since this time is considered most applicable to aircraft on final approach under low-visibility events. This time represents the time it takes a modern aircraft to reach the touchdown point on the runway from the outer marker which ranges from round 4-7 nm from the runway threshold; this is the latest time that a pilot would normally receive a runway visibility report from a controller. Also, algorithms for nowcasting RVR are potentially useful for reporting RVR when a sensor fails during poor visibility conditions.

Simple algorithms for projecting RVR values 1-5 min into the future were compared and evaluated by tabulating the percent of time the projected and actual VS measurements produced the same RVR category (0, I, II or III), the percent of time the predicted RVR category is at least one category less than the actual and when the predicted RVR category was greater than the actual. Select results were also presented in graphical formats. The nowcasts were based on: data coast; linear regression using 3-min, 5-min, and 9-min prior time intervals; and simple BW averaging over 2-min, 3-min, 4-min, and 5-min time intervals. In the linear regression method, σ was coasted with the current value if the slopes were negative.

The nowcasting method that appears to have the lowest percentage of predicted RVR category less than actual is the linear regression with data coast used instead if the regression slope is negative. BW averaging also produced percentages near those from data coast.

The results suggest that, compared to the standard practice of using current values of σ, safer visibility reports would derive from using regression-based processing of σ for RVR reports to pilots. It also appears that nowcasting of RVR out to as much as 5-min or longer duration may prove viable to insure short-term runway operational integrity when visibility sensors fail or are deemed unoperational.

Additional study of nowcasting of airport visibility conditions appears warranted. Such investigations should consider more sophisticated nowcasting algorithms, data from other locations, and differentiation by weather type and attributes.

Reference

T. A. Seliga, D. A. Hazen and S. Burnley, 2006: "Demonstration of the use of Runway Visual Range (RVR) visibility sensors for estimating snowfall rates throughout the airport domain", 12th Conference on Aviation Range and Aerospace Meteorology, American Meteorological Society, Atlanta, GA, 28 January-2 February.